

# ProFusion2 – Sensor Data Fusion for Multiple Active Safety Applications

S.-B. Park<sup>1</sup>, F. Tango<sup>2</sup>, O. Aycard<sup>3</sup>, A. Polychronopoulos<sup>4</sup>, U. Scheunert<sup>5</sup>, T. Tatschke<sup>6</sup>

<sup>1</sup> DELPHI, Electronics & Safety, 42119 Wuppertal, Germany, su.birm.park@delphi.com

<sup>2</sup> Centro Recherche Fiat, Italy, fabio.tango@crf.it

<sup>3</sup> GRAVIR-IMAG & INRIA Rhône-Alpes, France, olivier.aycard@imag.fr

<sup>4</sup> ICCS, NTUA, Greece, arisp@mail.ntua.gr

<sup>5</sup> Chemnitz University of Technology, Germany, scheunert@infotech.tu-chemnitz.de

<sup>6</sup> FORWISS, University of Passau, Germany, tatschke@forwiss.uni-passau.de

## ABSTRACT

The Preventive and Active Safety Applications project (*PReVENT*), contributes to the safety goals of the European Commission (*EC*). *PReVENT* addresses the function fields of *Safe Speed* and *Safe Following*, *Lateral Support*, *Intersection Safety* and *Protection of Vulnerable Road Users* and *Collision Mitigation* in order to cover the field of active safety. The majority of these functions are characterized by using perception strategies based on multi sensor platforms and multi-sensor data fusion. *ProFusion* as cross-functional activity has the responsibility to streamline the multi sensor data fusion in the functional field activities. This paper presents several aspects of the research work conducted in *ProFusion2* (*PF2*).

## KEYWORDS

Sensor data fusion, data fusion framework, multiple active safety applications

## INTRODUCTION

The Preventive and Active Safety Applications project (*PReVENT*), which is part of the Sixth Framework Programme, contributes to the safety goals of the European Commission (*EC*). *PReVENT* addresses the multiple function fields and covers the field of active safety. The majority of these functions are characterized by using perception strategies based on multi-sensor platforms and multi sensor data fusion. Hence, the strategy of *PReVENT* was to initiate a cross-functional subproject called *ProFusion* in order to streamline and to develop the subject of multi sensor data fusion in some greater degree of depth and in a more systematic approach as compared to the primarily function-driven subprojects. The role of *ProFusion* is to streamline the sensor data fusion inside *PReVENT* by, e.g. gathering requirements, defining certain standards and developing fusion algorithms, which should be used by the functional subprojects within *PReVENT*.

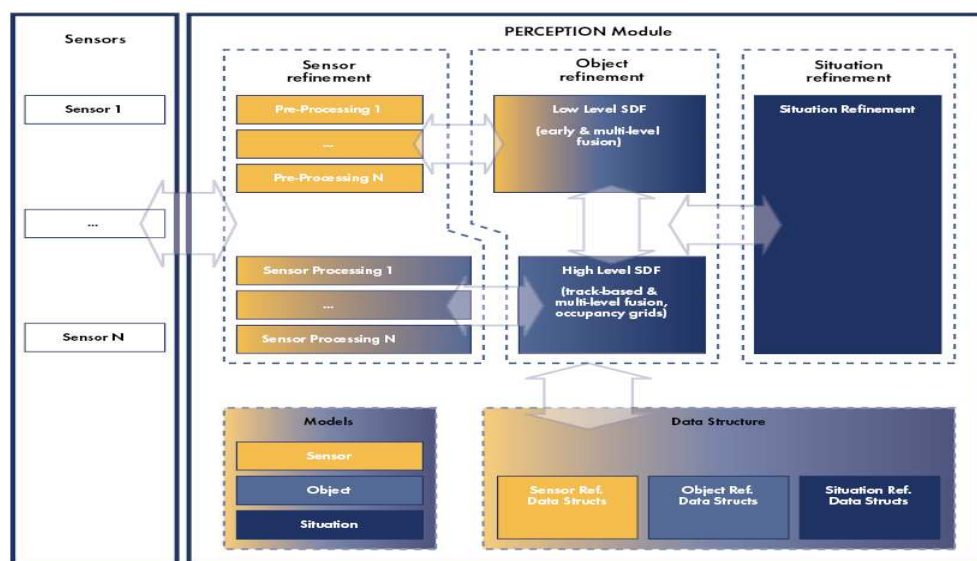


Figure 1 – PReVENT project structure and ProFusion2 consortium

In order to achieve the highest impact *ProFusion* has been implemented in two phases: During the initial phase of 6 months, *ProFusion1* has worked in close connection to all functional subprojects inside and even to activities and experts outside *PReVENT* to assess the state-of-the-art in the field of sensor data fusion and to derive the most urgent technical demands of *PReVENT* applications, which largely cover the technical challenges in the entire field of automotive environment perception and sensor data fusion. A key result of *ProFusion1* has been recommendations to continue the path of *ProFusion* concerning sensors and sensor data fusion. These recommendations have been chosen by the cross-functional sub-project *PF2*. This paper summarizes the system requirements, use-cases and four sensor fusion approaches of *PF2*. The reason to investigate into different sensor fusion directions is the high number of different multi sensor systems and safety applications.

## THE PROFUSION2 FRAMEWORK

The main scope of this section is to present the system requirements for the data fusion framework developed in the *ProFusion2* project and based on the general recommendation provided as final results by *ProFusion1*.



**Figure 2 – Sensor data fusion framework**

Based on the framework illustrated in the figure above, the main topics of this section are:

- The use cases, namely the vehicle prototype of the vertical sub-projects (VSPs), used as demonstrators within *ProFusion2*.
- The requirements that are divided in functional and architectural ones. Each requirement is satisfied by one research partner and applied to a particular application / demonstrator by an industrial partner

The requirements are the basis and the “guidelines” for the implementation of the appropriate data fusion algorithms, which are designed and developed using different approaches, but with the aim to go beyond the state of the art and to meet the needs of the applications developed in the VSPs of *PReVENT*.

## USE CASES

Since the fusion algorithms developed inside *PF2* are implemented and integrated into demonstrator cars, the use cases are represented by the prototype vehicles themselves. Each VSP develops a particular system and application; then specific parts of the data-fusion framework are tested here. In particular, the use cases until now envisaged in the project are shown in Table 1. As illustrated, the use-cases of *PF2* are constituted by 5 prototypes, implementing the applications [2] listed in the third column.

VSP	Vehicle Owner	Application	Requirements
COMPOSE	BMW	<ul style="list-style-type: none"> <li>Collision Mitigation (rear-end and pedestrians collision)</li> </ul>	R1, R2, R3, R4, R5
INSAFES	CRF	<ul style="list-style-type: none"> <li>All-around collision warning</li> <li>Collision mitigation</li> <li>Manoeuvre suggestion</li> </ul>	R2, R7
SASPENCE	CRF	<ul style="list-style-type: none"> <li>Safe speed</li> <li>Safe distance</li> <li>Traffic sign advice</li> <li>Speed limit info</li> </ul>	R1, R4, R2
APALACI	DC	<ul style="list-style-type: none"> <li>Pre-fire system for protection of car passengers</li> </ul>	R1, R3, R4, R5
COMPOSE / SAFELANE	VTEC	<ul style="list-style-type: none"> <li>Collision warning and mitigation (Applied to a truck)</li> </ul>	R1, R4, R5, R6

**Table 1 – Vertical sub projects applications and requirements**

## SYSTEM REQUIREMENTS

This section is focused on the presentation of the principal system requirements for the development of the data fusion framework inside PF2. Three main types of requirements have been identified as **Basic**, **Functional** and **Architectural** requirements (more details in [2]).

The **Basic** requirements consist in the necessity to obtain the same performances level obtained by the sensor data fusion algorithms developed in the VSPs.

The **Functional** requirements:

- **Requirement 1 (R1)** ⇒ Enhancement of the result of the environment perception in terms of the coverage of the same area by different sensors, e.g. higher accuracy or confidence level.
- **Requirement 2 (R2)** ⇒ Increase of the availability of actual perception results, e.g. coverage of blind area or extended operation.
- **Requirement 3 (R3)** ⇒ Increase of perception reliability, e.g. level of acceptable performance or extended conditions.
- **Requirement 4 (R4)** ⇒ Additional object properties, e.g. geometric features or fused tracking information.
- **Requirement 5 (R5)** ⇒ Request that such software modules comply with time constraints given by the application: in terms of latency time and update frequency, which should give a fast processing time, compatible with the specific application.

The **Architectural** requirements:

- **Requirement 6 (R6)** ⇒ Modular SW architecture: in order to have a flexible approach with the possibility to change computation modules and components.
- **Requirement 7 (R7)** ⇒ Possibility to configure, as input-configuration parameters, the numbers of sensors, the position of each sensor and the output measurements.

The need to have a platform flexible and configurable is extremely important; especially in *PF2* with several use-cases and all have different and changing sensor configurations. These requirements ensure a portable data fusion system which is suitable for multiple use cases.

All these presented requirements are regarded as most advanced and absolutely beyond the current state of art concerning the data fusion techniques ordinarily used. The main advantage would be the opportunity to tackle and to solve some problems nowadays more affecting the performance of so-called ADAS (and thereby to help their acceptance by the drivers); a clear example is the resolution of the overhead objects drawback, which can increase a lot the false alarms in a FCW (Forward Collision Warning) application, which may reduce significantly the operative range and applicative scenarios of such a function [1].

## SENSOR DATA FUSION APPROACHES

Due to the focus of the VSPs to their specific applications, *ProFusion2* has the role to bridge the gap to ‘original research work’. Thereby, a major objective of *PF2* is to improve the perception as a whole by developing promising data fusion concepts, which are summarized in the next chapters, because of the limited space (see references for more detail).

### EARLY FUSION APPROACH

The idea of the approach called *early fusion* is to combine pieces of information already on a early level to preserve apparently seemingly irrelevant sensor data, which would be separated out in the majority of cases by the sensors’ processing units. Essential for this approach is a joint data interpretation step with respect to a common model basis: As unbiased sensor data is used as fusion input, early fusion permits to process and interpret these early input data as a whole with the aid of modeled entities of the vehicle’s environment, i.e. fusion on the basis of unaltered information of all involved perception devices is provided.

In doing so, signatures of various sub-threshold findings in the data processing chain may interfere constructively and thereby contribute to an above-threshold result to form a distinctive, well-recognized object instantiation. Thus, an increase of robustness, reliability and consistency in the environment perception is expected as the input from an individual sensor can be processed in view and with the help of the other sensors from the very beginning.

The BMW COMPOSE demonstrator vehicle ([3], [4]) provides the basis required for the early fusion perception system: Additional to its original configuration including a laser scanner, two short range radar, two long range radar devices and a far infrared camera, a bifocal stereo camera system and a 3D range camera added for *PF2* deliver their slightly pre-processed/raw sensor data to the fusion system.

Due to the promising results achieved within COMPOSE [4] research and development activities are followed up within *PF2* to put the early fusion method into a broader context – the *PF2* fusion framework [5]. In doing so the COMPOSE early fusion system will be expanded focusing on the following main tasks:

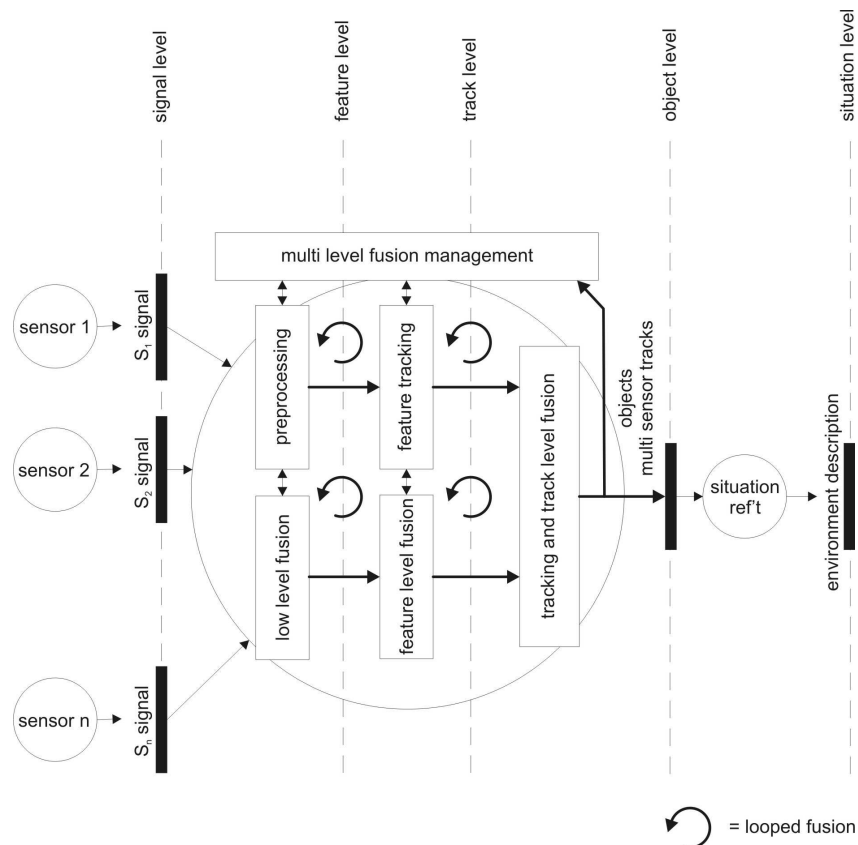
One objective of *PF2* is to integrate an approach spanning data structure with a common output interface for the environment description [6]. This should facilitate the exchange of information and processing results within the fusion architecture and ensures the compatibility with different situation analysis algorithms. These activities within *PF2* also contain studies concerning the assessment of different subsets of the sensor platform with regard to accuracy, robustness and reliability of the perception output.

Additionally further work is spent in the field of feature models. As these special object (feature) models are essential for the early fusion methodology and its fusion procedure [4], the work within *PF2* concentrates on an extension for the extended *PF2* sensor set and a refinement of already modelled objects takes place. In conjunction to this the basic data association and filter algorithms used so far are subject of further development. Moreover a theoretical framework for combining the empirical and model-derived information in hierarchical manner is investigated in to achieve reliable confidence information with respect to the algorithmic result at runtime without exhaustive statistical testing and evaluation (confidence measures). The original contribution of *PF2* is basically the joint of a hierarchical object setup with classical stochastic approaches for confidence estimation.

### MULTI LEVEL FUSION

In the multi level fusion approach information about objects are distributed over different levels of abstraction and are fused within and between these levels too. In detail these levels are based on the definition of the definition in the JDL-model and include signal level, feature level, track level, object level and situation level.

Raw or pre-processed data coming from different single sensors can be found at signal level. They are transferred to the processing chain where they are processed and fused with data from the same, higher or lower level.



**Figure 3 – Multi level fusion functional architecture**

The chosen level of fusion is strongly connected to the specific object and also dependent on the model of the object itself. For that reason for every object a certain hierarchical fusion strategy can be defined. In doing this the tracking of an object can be supplied with data from tracked features, untracked features and from signal level.

By the use of multi level fusion it is possible to introduce back loops between the levels. Back loops can be used to return to a lower level of abstraction for reprocessing certain data or to adapt fusion parameters. A special case of multi level fusion is a processing on adaptive chosen levels. This allows the fusion strategy and the selection of a certain fusion level to be dependent on the actual sensor data and the observation situation of an object. That's why a better processing strategy can be achieved in most cases.

The use of a valuation of intermediate results of the single levels of abstraction introduces the need for combining single values of confidence in lower levels to values of confidence in higher levels. This is strongly related to the combination of primitive objects in lower levels to less primitive objects in higher levels of abstraction.

Multi level fusion implements high-level to low-level and/or low-level to high-level fusion strategies and makes use of parallel or sequential processing chains. It includes sensor information, feature information and procedural knowledge in a model representation. Challenges in using multi level fusion are to build a unified data structure which is able to handle the given and acquired knowledge, to find suitable features for robust object description and to come up with methods to overcome and reduce the computational complexity of the system.

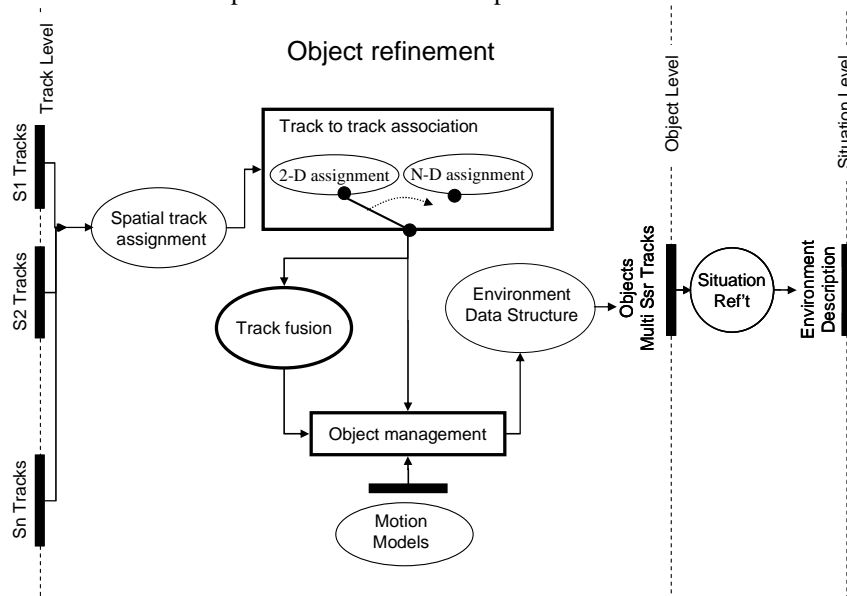
## TRACK BASED FUSION APPROACH

The track-based fusion within the object refinement layer is a distributed approach. It assumes that tracking is carried out inside each individual sensor or system, and the tracks feed the track level fusion algorithms. It can be applied to automotive sensor networks with complementary or/and redundant field of view. The advantage of this approach is that it ensures system modularity and allows benchmarking, as it does not allow feedbacks and loops inside the track processing.

Research and development for track level fusion is focused on developing innovative algorithms in the area of multidimensional (N-D) track-to-track association, track management and track fusion. Expected results from these efforts are higher consistency and the avoidance of spurious or invalid perception information. The output of the track level fusion is aggregated tracks in the union of the sensor field of views.

The track level fusion architectural modules shown in Figure 4 imply that a set of track arrays are entering the fusion system while the output of object refinement process is consisted of the fusion object list. The internal functionalities in this architecture are the association (spatial track assignment and 2-D and N-D association), the track to track update (fusion) and the fused object management. All these sub-modules are described in detail in this section.

The fusion area track assignment is the first function that is imposed to the tracks when they are entering the fusion system. The main objective of this is to decrease the computational load of the overall procedure and also to ensure the configurability and the interoperability of the procedure. A set of sensor configuration parameters are necessary for this module to work properly. The main process of this module is to separate the sensor coverage area around ego vehicle and consequently separate available tracks. These areas could be blind areas not observed by any sensors, areas with one sensor and areas observed by multiple sensors. The main result of this process is to subdivide a fusion problem into sub-fusion problems.



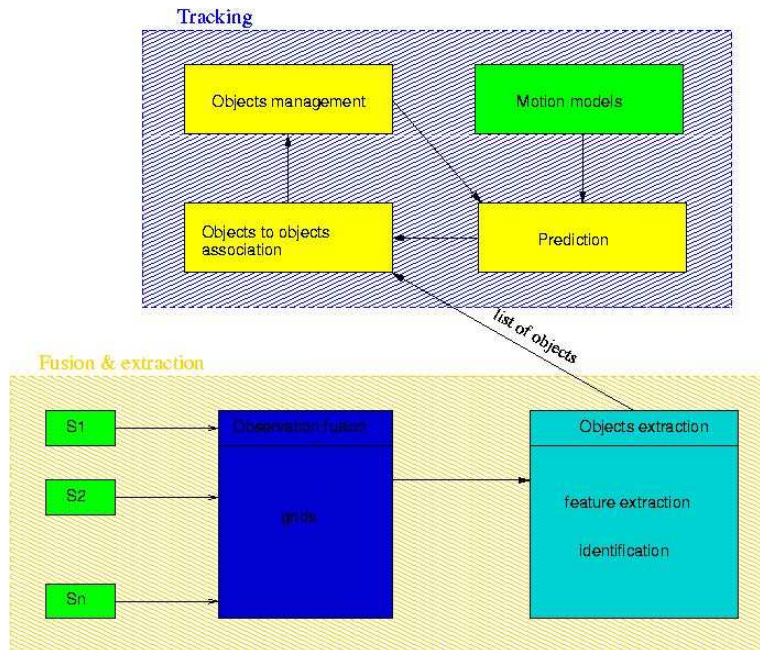
**Figure 4 – Track based fusion functional architecture**

The tracks that belong to areas without or single sensor surveillance are passing to the output without any additional processing. For tracks that are within the common multi-sensor areas (2 sensors or more) an association measure will be defined. This metric represents the hypotheses for association between tracks, and then the relative association matrix or other metric passes to the next level where the track to track assignment takes place (track to track association). In the case of 2 sensors tracks the 2-D association problem is solved. In the case of tracks coming from more than 2 sensors then the solution to this problem the N-D with N to be 3 more takes place in this module. The assignment tracks (2 or more) that come from the output of the assignment modules are fused by the track fusion module. They are updated and generate a fused object state and covariance that replaces the existing sensor level tracks.

Within the object management module the fused and the non-fused tracked objects are formatting the final object list output for the object refinement process. All the objects have an ID and in this module the initialisation, updates, deletion of objects based on ID information take place. Moreover, this module will handle, in a final step, object management issues such as duplications of objects, blind areas objects, transition of objects between different areas and all other relevant problems that might appear.

## GRID BASED FUSION

The idea of the approach called *grid based fusion* is to develop a new framework to multi-sensor fusion called occupancy grids (OGs) [7]. An OG is a stochastic tessellated representation of spatial information that maintains probabilistic estimates of the occupancy state of each cell in a lattice.



**Figure 5 – The grid based fusion architecture**

In this framework, each cell is considered separately for each sensor measurement, and the only difference between cells is the position in the grid. The main advantage of this approach is the ability to integrate several sensors in the same framework, taking the inherent uncertainty of each sensor reading into account, contrary to the geometric paradigm. The major drawback of the geometric approach is the number of different data structures for each geometric primitive that the mapping system must handle: segments, polygons, ellipses, etc. Taking into account the uncertainty of the sensor measurements for each sequence of different primitives is very complex, whereas the cell-based framework is generic and therefore can fit every kind of shape and be used to interpret any kind and any number of sensors.

For sensor data integration, OGs only require a sensor model which is the description of the probabilistic relation that links a sensor measurement to a cell state, occupied (occ) or empty (emp). The e-Motion group (<http://emotion.inrialpes.fr>) of GRAVIR Laboratory and INRIA Rhône Alpes has a strong background in building sensor models to map environment using OGs for Intelligent Transport Systems [8][9].

In *ProFusion2*, we are developing new sensor models for high level fusion in collaboration with VTEC and for low level fusion in collaboration with DaimlerChrysler [10]. As our objective is to have a robust perception using multi-sensor approaches to track the different objects surrounding a car, the grid based fusion approach is combined with multi-objects tracking techniques. The whole architecture is depicted in Figure 5. This architecture is composed of two distinctive parts: a Grid based fusion and Extraction level and a Tracking level. In the first level, we perform fusion of data given by different sensors to build a map of the current environment .i.e. a snapshot of the current environment. In a second step, using this map, we search the objects currently present in the environment. Finally, in the tracking level, we associate this list of objects with the list of pedestrians previously present in the environment. An implementation of the complete architecture could be found in [11].

## RESULTS

As result the *ProFusion2* achievements will be implemented, integrated and evaluated in open-loop real-time environments, and ultimately utilised in the closed-loop on-board systems of the corresponding function demonstrator vehicles from the application-oriented *PREVENT* subprojects. For these purposes these experimental vehicles are equipped with different sensor devices, like vision and FIR cameras, short and long range RADAR sensors as well as LIDAR devices. This paper concentrates on research results conducted by the *PF2* activity in the second year of *PF2*. The algorithm development of all approaches is based on the *PF2* framework / architecture, which has been already presented in other publications. The innovation of *PF2* is that, based on the *PF2* framework / architecture several multi sensor data approaches are developed and multiple active safety applications are derived. Hence the developed sensor data fusion algorithms are proven to be robust, but also gain advantages to single application approaches.

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