# D-FUSE

## Publishable Executive Summary

# Data Fusion in Urban Sensor Networks

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# 1 Introduction

This document summaries the activities and results of the project Data Fusion in Urban Sensor Networks (D-FUSE) carried out by the consortium: THALES Nederland B.V. (The Netherlands), Bumar Elektronika S.A. (Poland), SAAB AB (Sweden), THALES Air Systems S.A.S. (France), Datactica (Finland) and Data Fusion International (Ireland).

This project is part of the Joint Investment Programme on Force Protection (JIP-FP) under the framework of the European Defence Agency (EDA). It is funded jointly by the contributing Members of the JIP-FP programme, and the contractor and subcontractors.

# 2 Objectives

D-FUSE addresses several research and technology issues around the central subject of data fusion within networks of sensors in the urban environment. The project's main objective is to help future development of effective, robust and reliable multi-sensor data fusion engines to provide the required situational awareness for the protection of forces operating in the urban environment. D-FUSE assesses the added value of fusing sensor and context data ('outside information' from other sources than sensors) for force protection, using both traditional and novel sensors. Another objective of D-FUSE is to enable automatic fusion of 'hard' sensors data with more 'soft' context information.

D-FUSE focuses on urban areas, which are of increasingly crucial importance for military operations. Achieving superior situational awareness in the urban environment is not easy: the urban terrain is a multidimensional, dynamic and dense environment. The threats come from lower airspace as well as from ground targets. Furthermore, military forces in the urban environment have to deal with the presence of many neutrals and might be involved in a wide range of operations, ranging from peace keeping operations to high intensity combat. D-FUSE proposes solutions to improve the situational awareness while taking into account the complexity of the urban environment.

The technology innovation of the project is in defining new data fusion architectures and data fusion algorithms that enable the intelligent combination of information from multiple redundant and/or complementary sensors, and from context information (maps, intelligence reports), to create improved situational awareness.

# 3 Project organization

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# 4 Project Results

For the first investigations conducted during the D-FUSE project, a clear separation between networks of capable sensors and networks of simple sensors has been maintained. Networks of capable sensors would typically use less than 10 sensors. Networks of simple sensors can have much more than 10 sensors. In later stages, these approaches have been mixed, allowing the benefits of both sensor types to be combined. In addition, high level functions of data fusion engines were investigated.

For both the capable and simple sensors, the D-FUSE consortium also analysed how ‘outside information’, hereafter referred to as ‘context data’, can be best employed in the data fusion engine to improve detectability, tracking performance and continuity, and/or the classification or identification of objects.

Finally an overview of various implementation issues was made.

## *4.1 Networks of capable sensors*

Data fusion for capable sensors presents advantages for both ground and low level airspace segments. Because the urban environment includes many new challenges and is a highly anisotropic environment, new tooling had to be developed to assess the added value of data fusion for detection, tracking and classification, for radar, infrared and/or daylight cameras. The added value of data fusion has been demonstrated by using the innovative analytical methods based on Cramér Rao bound computation and processing techniques which have been extended for the multi-sensor case.

The D-FUSE consortium also addressed how information fused from radars, other sensors and context sources (e.g. weather, 3D city map, intelligence, etc.) can help the localisation of Rocket, Artillery and Mortar (R&M) launchers and can support threat identification, as well as speeding up the process of decision making. An outline of track detection/initiation problems was made and two multi-radar track initiation algorithms were analysed, based on

Multiple Hypothesis Tracking (MHT) and Hough Transform (HT) principles. Then, a concept was developed for a Counter-Rocket Artillery and Mortar (C-RAM) data fusion engine. Another significant finding is that when context data is included, it can offer significant benefit for situational awareness. This is especially true for the ground segment where the limitations imposed by the urban environment are the greatest.

Classification was a major subject of the D-FUSE project, next to localisation and tracking. The D-FUSE consortium has identified that fuzzy logic presents many advantages regarding data fusion in the urban environment. First, it enables the control of the error rate, by taking into account the measurement errors. Next, the data fusion is realized using simple ‘min’ and ‘max’ operators: the required computational power is therefore very low. Finally, no learning base is needed. Results of the analyses were confirmed by the simulations.

Finally, three different types of network architectures were investigated: the fully centralised, the fully distributed, and the hybrid architectures. In conclusion, the fully centralised architecture has the best performance; however the processing load as well as the communication load might impose a bottleneck for a particular system. Both the fully centralised and the fully distributed architectures have the disadvantage that the local sites do not have any fusion result at hand. This implies that the accurate fused tracks cannot be used for local decisions, such as improving the setting of modes and waveforms of sensors. Hybrid fusion architectures were then discussed to solve, to some extent, the disadvantages mentioned above. Hybrid architectures can make a trade-off between fusion performance and communication and processing load. The resulting architecture system may seem a bit more complex (see Figure 4-1); however communication requirements are much smaller and redundancy is improved with respect to the centralised fusion architecture.

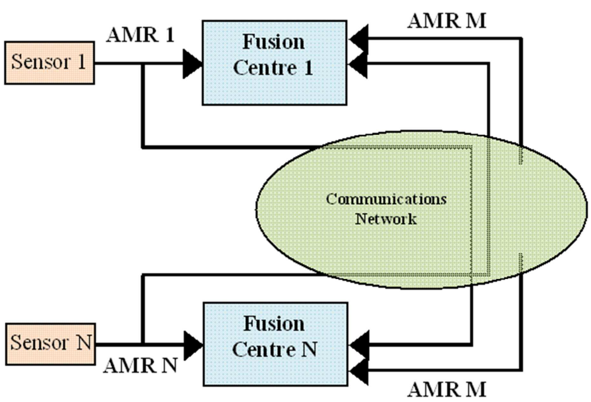


**Figure 4-1: Ultimate Hybrid architecture**

## *4.2 Networks of simple sensors*

Combinations of simple sensors can create information of high value to build up situational awareness. However, obtaining good situational awareness in the urban environment using networks of simple sensors and a fusion engine is a problem of enormous complexity. The most important obstacle is actually cost – the cost for good sensors (in contradiction to our definition of 'simple' sensors), the cost for high bandwidth communications, the cost for sufficient numbers of sensors and network nodes, the cost for powering the networks and the processors and, of course, the cost for developing the very complex and still immature fusion and other data processing technologies.

The first aspect investigated during the D-FUSE project for the networks of simple sensors focused on detection, localisation and tracking of persons and vehicles. A model for analysing the trade-off between bandwidth and power consumption in the wireless network was developed. Techniques were analysed for processing stereo webcam pictures (for indoor tracking and people counting) and for recognising vehicle sound information with acoustic sensors. As with networks of capable sensors, exploiting constraints, such as those given by maps, is very helpful and should be integrated into the tracking. Furthermore, a market survey of dedicated sound and video analysis systems, e.g. for sniper detection, was carried out, which can be a valuable extra source for the fusion engine.

The second aspect examined for the networks of simple sensors concerned how context information can be used to support tracking and classification (this work has largely been done jointly with the work on networks of capable sensors). Three approaches have been analysed: usage of map data, ontologies and Bayesian Networks, in connection with particle filtering. Simulations revealed that combining particle filtering with context information is very fruitful and promising.

The D-FUSE consortium finally recommended a network and fusion architecture for networks of simple sensors. The architecture should consist of wireless networks where data is collected into a central fusion node. The data should be as raw as possible given the bandwidth. The network should support two-way communication for sensor control.

## *4.3 Networks of capable and simple sensors*

Simple and capable sensors can have widely different characteristics, such as attributes, coverage, timing and type. As a consequence, they can provide very different types of data. The fusion of these inhomogeneous data can therefore be difficult or even impossible. The D-FUSE consortium explored the following solutions:

- Firstly, fusion of measurements with tracks was investigated. It can be achieved with the use of tracklets: the latter are data with a lower degree of processing than tracks.
- At the classification level, three main methods (possibility, probability and evidence theory) can be used to merge features inside a sensor or in a local fusion centre. These local fusion centres can use different methods for merging the classification data depending on the requirements: some transformations between possibilities, probabilities and evidence were defined during the D-FUSE project.

The D-FUSE consortium also proposed an innovative method to optimise sensor network configuration, i.e. the definition of the optimum sensor suite and the optimum sensor positions. It was demonstrated that optimisation of a mixed network can be successfully performed by means of a genetic algorithm, by selection of a proper criterion function.

Finally, different architectures for networks composed of capable and simple sensors have been proposed. It was shown that hierarchical architectures present a lot of advantages.

## 4.4 Ontology

The consortium noticed that some context data can be best represented in relational database format (both GIS and quantitative data), and some represented in ontologies. An ontology is a formal description of a domain. It can be done in many ways, but the most popular today is by using the Web Ontology Language (OWL). The first ontology that incorporates context data has been designed, implemented and tested during the D-FUSE project. Later in the project, the consortium explored issues relating to the representation of semantic knowledge about the urban environment and how to use this to understand what is occurring. In order to represent higher level knowledge, such as cultural events, a second ontology was implemented. Two types of reasoner applications were next developed.

One key advantage of an ontology-based approach to situation awareness, over a database approach, is that once facts about the world are stated in terms of the ontology, other facts can be inferred using an inference engine. This is particularly important for situation awareness since it heavily relies on the knowledge of relationships. Because there are so many possible relationships, it is impractical to expect that procedures could be written for all potential relationships. Another finding is that as more facts (based on the output of sensor fusion or higher-level fusion functions) are built up over time, and more context data are represented in the ontology, there is a wide variety of things that can be deduced, and this increases as more data are added. A downside to ontologies is their complexity. The area is made up of several standards and many vendors and tools that implement the standards in different ways, often with poor documentation.

## 4.5 High level function of the data fusion engines

The D-FUSE consortium has addressed a range of approaches to high-level data fusion for situation assessment. The aim is to assist an operator by analysing lower level data in combination with other types of data (e.g. context data) to automatically perform some assessment of the situation that would normally be the responsibility of the operator.

The first high-level data fusion function analysed by the consortium was anomaly detection. The D-FUSE consortium investigated the problem of how to automatically measure the normalcy of a situation and detect anomalies. A simple sensor model was implemented in the simulation platform to provide realistic input to the anomaly detection and a number of different anomaly detectors were studied. Overall, the main finding from the work on anomaly detection is that the results of anomaly detection can be used both for alerting an operator and as input to an ontological reasoning system. However, more research and development is needed before the technology is ready for an operational system.

The second high-level data fusion function considered was assessment of the enemy’s likely intent. Based on the knowledge of enemy tactics provided by intelligence and on enemy movements provided by the sensor network, the objective of this function is to indicate to the operator the likely intent of the enemy force. It was shown that reachability analysis can be used when planning own troop positions, sensor and checkpoint locations, evacuations and logistics support, among others

The third innovative high-level data fusion function considered by the D-FUSE consortium addresses the automatic generation of continuous tracks from incomplete sensor coverage. High-level fusion of capable sensor data with both context data and simple sensor data, was proposed to overcome some of the shortcomings due to blocking. It was shown that a track filter that is implemented with a particle filter can benefit from the provision of context data.

A key conclusion of the work on high-level functions of the data fusion engines presented by the consortium is that it is indeed possible, using a variety of approaches, to make automatic assessments about both specific aspects of situations (e.g. anomalies), and more general aspects of situations (e.g. enemy tactics or situation reasoning).

## *4.6 Implementation issues*

An overview of various implementation issues was made, and resulted in recommendations for the different network types (networks with simple, capable and mixed sensors).

# 5 Recommendations of future activities

The D-FUSE consortium recommends future research be conducted on the following subjects:

- Tracklets enable the fusing of data that are correlated and to decrease the amount of data to transmit. A new topic of research is the combining of particle filtering with tracklets;
- Fusion of inhomogeneous, and also sparse, data should be further studied in order to enable the merging of inhomogeneous data at detection, tracking and classification level;
- Networks with simple video cameras, such as mono or stereo webcams, have a great potential to provide situational awareness. It is however still not clear how to best process and disseminate the data considering power and bandwidth limitations; this would be well worth a study;
- During the D-FUSE project, it was demonstrated that optimisation of a mixed network can be successfully performed by means of a genetic algorithm, by selection of a proper criterion function. Sensor network configuration optimisation using additional constraints improving system performance should be further investigated;
- It was also assessed during the project that both sensor and data fusion performance decrease with an increasingly dense and populated scenario. Non-target oriented surveillance is one alternative technique to cope with such situations and should be explored;
- The D-FUSE consortium advises the continuation of investigations into the combination of federated and hybrid ontologies in order to link different representations of context data;
- The performance of the joint tracking and classification method proposed within the D-FUSE project for targets behaviour recognition applications should be assessed in the context of abnormal or unexpected behaviour detection;
- Finally, the D-FUSE consortium recommends future research be conducted into Sensor Network Management and advanced network architectures in order to further optimise data fusion performance.

The D-FUSE consortium also advises higher TRL developments:

- For multi-sensor RAM tracking and recognition;
- For anomaly detection, and;
- For context data implementation in sensors.

# 6 Conclusions

D-FUSE being a low TRL study, the D-FUSE consortium has chosen to address a large variety of innovative and original ideas. D-FUSE therefore has dealt with a large array of subjects relating to data fusion in the urban environment. D-FUSE investigated new data fusion concepts that clearly led to an improvement of the situational awareness for the protection of forces operating in urban areas.

It is well known that sensor data fusion presents advantages for target localisation, tracking and classification. D-FUSE has not only confirmed this for urban applications but also addressed the optimisation of the sensor networks. In addition, D-FUSE added new dimensions to data fusion by assessing context data fusion next to the more traditional sensor data. Moreover, multiple modern tracking and classification techniques were investigated and their performance analysed in the urban environment. High level functions, such as anomaly detection or assessment of enemy intent, were created to further improve situational awareness.

Last but not least, the investigations conducted within D-FUSE have led (and will very likely lead in the near future) to exciting new fields of research: sensor network density optimisation, indoor tracking with extremely simple sensors, fusion of ‘soft’ and/or dynamic context data, and ontology integration with the data fusion engine’s high-level functions, to mention a few.