Sensor Suites for Future Autonomous Unmanned Aerial Vehicles

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OVERVIEW

In the next few decades missions of unmanned platforms will be processed with an increasing level of autonomy. This affects ground, maritime and airborne platforms and their sensors in the military and even civil market. This presentation will deal with the key drivers and enablers for the realization of a sensor suite for autonomous mission execution. A functional architecture of a development, simulation, test and integration system, and the system under development will be proposed. Even though the presentation focuses on airborne platforms, which are also applicable to a wide range both civil and military applications, for reconnaissance, surveillance, collaborative processing and target acquisition.

More and more missions which had to be executed in segregated airspace will be performed in non-segregated airspace. Procedures and operations in ATC/ATM will exist and the platforms will be enabled to solve sense and avoid problems autonomously. Also former ground-based reconnaissance and surveillance applications will be transferred to the aerial sensor platforms. New processing hardware and software technologies will be available which will be the key enablers for the realization of new applications and successful execution of new missions which were formerly not be possible at all. The platforms will reach a high degree of agility and autonomy. An information and knowledge grid will be available to which these platforms will transfer generated data and information. That way, a common operational picture will be created from which other members may benefit in order to fulfill their mission goals more directly, safely, effectively, and efficiently. Obviously in a large grid with many information consumers and providers a huge amount of data will be created and requested at any point in time. It is therefore of paramount importance that only relevant data is transferred to the grid in order to prevent overloading of the available network capabilities.

Additionally, mechanisms will be provided such that each grid member will get the right data in the right quality at the right time and at the right place. This encompasses also the availability of the best-suited sensor mix for a particular mission. It is therefore obvious that sensors must be easily exchangeable and adaptable. Hence, plug and play solutions are necessary in order to achieve the best sensor mix for a specific mission. A common representation of the platform's, sensor's and sensor suite's capabilities is required. The presentation focuses on this aspect.

Autonomous operations require also the knowledge of the current situation. This comprises the situational awareness and the creation of a meta model of the platforms operating environment, such as weather, time of day, the operational picture, the status of the platform, its supporting subsystems, the sensor suite, available capabilities and constraints. A wide range of data, as well as the collected knowledge during the mission as the pre-stored data must be assessed and related to each in order to provide autonomous mission execution. This encompasses the application of a wide range of research areas of knowledge representation within the sensor suite which must be accessible and interrogateable by the platform itself or even by other connected platforms.

In order to keep pace with a fast growing technology, the development, test and integration environment must be modular and must be capable to integrate state-of-the-art components. A solution how this is addressed by EADS Defence Electronic within a Rapid Prototyping And Simulation (RPAS) Approach is shown at the end of the presentation.

1. CHANGING SCENARIOS

The last decade is characterized by fundamental modifications to the operation and self understanding of the armed forces. While the political and social environment is changing dramatically, new techniques and technologies are offering new concepts of operation.

The cold war is replaced by asymmetric warfare, peace keeping operations and fight against terrorism. National or regional economic cluster are substituted by global networks of strongly reciprocal dependent companies and political economics.

At the same time communications technologies and information sharing techniques are offering new opportunities to coordinate operations on both sides – the national or international governmental forces and their opponents. But while during the cold war the opponents and threats were quite easy to identify, today neither the threats nor the opponents are easy to detect.

Therefore - to identify these new kinds of threats and opponents - a rethinking on the use of sensors, sensor mixes and on new techniques / technologies for detection and identification is demanding. As a major topic for Shared Situation Awareness (SSA) the armed forces need sensors and appropriate techniques and technologies to detect and identify.

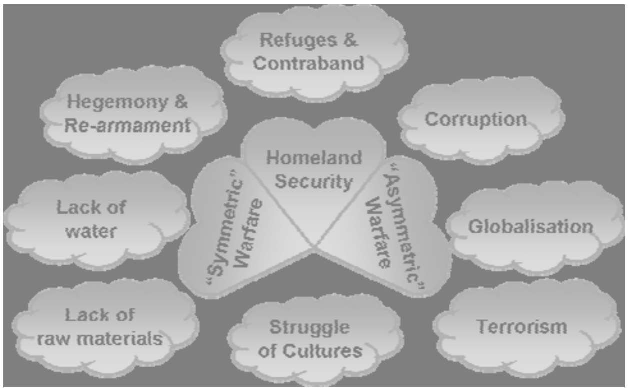


Figure 1: Changing Threat Scenario

Since ever information superiority is the key demanding quality for success. Today information and communications technologies are opening new opportunities to release information dissemination and communication between commanders. Thus self organization of commanders within their task frames gets a new and powerful meaning.

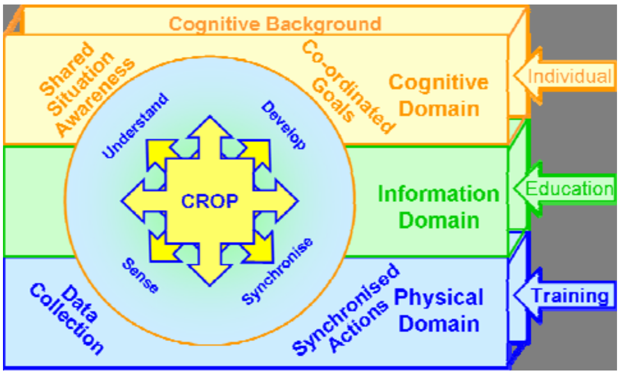


Figure 2: Sense - Understand - Develop - Synchronize

But self organization - the synchronization of activities - is only possible, if commanders have commonly developed and coordinated goals, which is only possible, if they have a common understanding of the situation i.e. if they have a Shared Situation Awareness.

Shared Situation Awareness is based on a common available situation picture (SitPic) or Recognized Situation Picture for space (RSP), air (RAP), ground (RGP) and maritime (RMP). The recognized situation picture is based on all available information on the operation area, comprising (near) real time information and non real time information (e.g. intelligence information, geographical information, CONOPS, commanders intent, etc.). The (near) real time information is mainly based on sensor data and exactly here are coming up new challenges:

The scope of opponents has widened, while in the past primary military equipment and soldiers had to be detected and identified, today's scope for detection and identification is enormously enlarged. The task is not only to track red, blue, grey and white forces, but to detect and identify civil equipment and persons and to prognosticate their intention.

The threats are extended, encroachments against the population and the armed forces have their origin in civil persons and equipment (e.g. terrorists with improved explosive devices).

Autonomous remote sensors / sensor suites should provide information, if not even knowledge or wisdom instead of pure data to the information network. Hence intelligent data processing und fusion methodologies are required including the capability to steer and control the sensors.

Autonomous operating unmanned vehicles need a situation picture to accomplish their mission.

The missions of the armed forces have changed, which demands combined operation with allied forces and cooperation with governmental and non governmental organization. This raises additional challenges for information exchange and shared situation awareness.

Modern warfare requires a huge information exchange, which runs into it's limitation due to unavailability of communications channels and bandwidth.

All these challenges could be summarized in the chain (see FIG 2):

Sense – Understand – Develop - Synchronize

The process is based on the common understanding of the situation, which leads to shared situation awareness. The situation in the operation area is described by background information and actual sensor data. Hence to facilitate shared situation awareness one must start with:

- appropriate sensors / sensor suites
- appropriate data fusion methodology
- appropriate communication means and

procedures

Therefore a Sensor Suite Experimentation Program is supposed to answer the fundamental question:

How the situation awareness of armed forces commanders could be enhanced by using the appropriate sensor suites with data fusion methodologies and communications means.

2. SENSOR SUITE EXPERIMENTAL PROGRAM REQUIREMENTS

An EADS experimentation program is the right way to define the way forward in

- sensor technology,
- sensor data and background information fusion,
- autonomous remote sensor operation,
- information provisioning into and within the information grid,
- communications.

The experimental program includes various phases and steps. Starting with theoretical work and going over to test concepts in a simulation environment the program leads to hardware-in-the-loop experimentation using prototypal solutions for specific demands. Thus the program will be beneficial for the realization of Network Enabled Capabilities (NEC).

For the experimentation program within is essential to start with the theoretical work to make up the minds

- for understanding the sensor demands,
- for clarification of the actual situation,
- for identification of the capability cabs,
- for the development of new concepts and
- for planning the further experimentation program.

In addition, concept development and experimentation in a simulated environment is not only a cost efficient way to prove ideas and to select the best for further development and hardware in the loop experimentation, but it offers the opportunity for industrial, national and international test bed cooperation.

The experimentation program is line with other European programs, such as LoI-NEC and LoI-DF, which are analyzing techniques and benefits of shared situation awareness (NEC) and data fusion (DF) but are not focusing on the means and ways to get the relevant data. Hence a sensor suite experimentation program would fit very well in the overall scope of Network Enabled Capabilities (NCO) and Network Based Operation (NBO).

The following gives a first hint how sensor suite experimentation program will be used to answer operational questions.

The experimentation program is applied to sensors and sensor suites on manned and unmanned vehicles for air, ground and maritime operation as well as on information gathering and fusion of available information from many sources. Basically the program includes overall architectures applicable for these different target applications.

Focus for the first applications is the Future Autonomous Unmanned Aerial Vehicle. From this starting point specific requirements for the operation of unmanned vehicles in their environment and the special demand of introducing them in the experimentation are evaluated always with the aim to transfer them into generic overall architectures. This comprises general considerations such as:

- Scenarios and requirements,
- Sensor capabilities,
- Sensor suites and data fusion,
- Networks and communications,
- Test bed concepts,
- Experiment definitions.

Scenarios and requirements are assessed to create a common understanding of the actual and future situation with respect to:

- scenarios, which information is desired, i.e. what should be detected / identified,
- information dissemination, i.e. which information should be available to whom, including time constraints

Sensor capabilities defines today's and upcoming sensor technologies to detect and identify relevant opponents and threats. It is an inventory of sensors and related capability data, i.e. which property / feature is measurable by which method and the attributes of the method (e.g. range, probability, confidence). Sensor capabilities include required sensor performances for autonomous operation of unmanned vehicles.

Sensor suites and data fusion analyze opportunities and develop concepts for sensor suites if data fusion / background information fusion processes are taken into account:

- enhancement and new opportunities of sensor suites through the use of appropriate sensor data fusion process,

- enhancement of information extraction through fusion with background knowledge,
- additional aspect of sensor data fusion process, such as automatic classification and identification process, automatic target recognition (ATR), geo referencing and change detection
- active / passive radio frequency identification (RFI) and bacons
- data pre-processing and reduction using sensor fusion process for information extraction (communications data rate reduction by intelligent data and background information fusion)
- pro and cons of platform vs. network based sensor fusion process
- data processing and fusion processes for autonomous vehicle operation

Networks and communications embed the use of sensor suites in a network centric operation (NCO) approach:

- definition of information classes (ISR) and time criticality
- definition of information / data dissemination processes and procedures for different information classes and time critical information / data (cooperation with governmental institutions (user) required)
- development of communications concepts

Test bed concepts define the experimentation test bed, including (but nor limited to):

- overall test bed concept,
- architecture,
- analysis means, tools and procedures,
- simulation means and tools,
- opportunity to use measured life data,
- hardware in the loop,
- netting of national integrated test beds (governmental as well as industrial).

Experiment definitions detail the frame for experimentation projects, including the frame for test procedures and evaluation criteria.

With the demonstrator the necessary technologies will be examined to develop a sensor related processing in order to increase the use of networking sensors for application with real-time requirements such as time sensitive targets and close air support.

3. SENSOR SUITE DEMONSTRATOR DEVELOPMENT PROCESS

First the Definition Phase details the required functionality. A model driven approach is selected to verify requirements in use cases. Then the project will concentrate on a simulated environment including scenario and platform simulation and simulated sensors. Data fusion and information extraction models will be assessed and simulated. The simulation will demonstrate a target detection, classification and identification with cooperating sensors (SAR/MTI, EO/IR, ESM) and the necessary correlation and fusion path in order to find an optimized sensor mix with high probability of target identification. Sensor and platform mission execution functions will be model driven implemented.

In the next step the sensors and models will be replaced by real sensors and algorithms to demonstrate and test the sensor hardware and the data fusion and information extraction functionality on a future onboard processing system. Sensors and platform basic functions (sensor pointing, platform attitude, target behavior) must be stimulated.

In the last step a complete sensor-suite with an assessed sensor-mix will be integrated as payload for flight test with target identification.

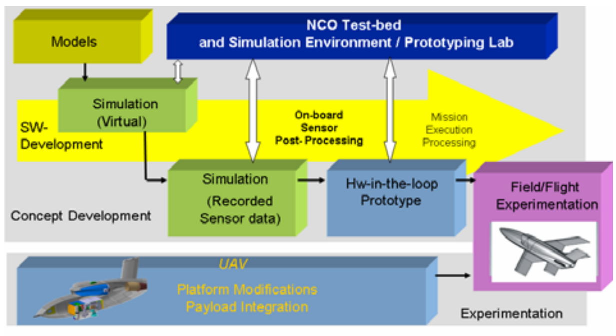
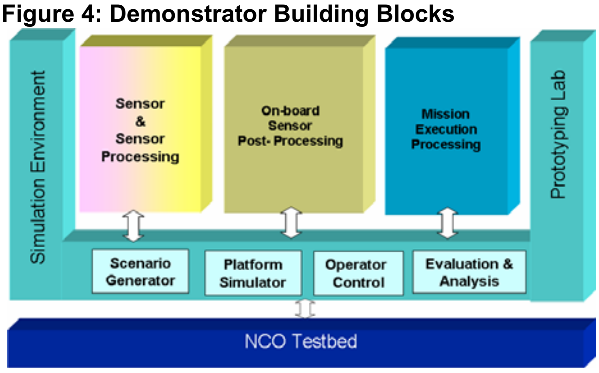


Figure 3: Demonstrator Development Process Demonstrator Building Blocks

The main purpose of the demonstrator is to have an adequate development capacity available and to demonstrate different sensor combinations under a wide range of operational aspects.

Figure 4: Demonstrator Building Blocks



Sensor & sensor processing, on-board sensor post-processing and mission execution processing are the core building blocks of the demonstrator. This is the focus of the demonstrator aiming to have finally on-board hardware available for platform integration and test. The surrounding infrastructure containing the simulation environment and the prototyping lab supports the development of hardware equipment and software functions to fulfill mission-specific requirements. In more detail the prototyping lab includes scenario generators, platform simulators, operator control stations and evaluation and test tools. A connection towards a network centric operations test-bed is added to satisfy system of systems aspects in order to make sure that the demonstrator can be developed and tested in operational, joint and combined scenarios with other platforms and systems.

3.1. Modeling

The sensor suite shall satisfy a wide range of functional requirements within a complex system of systems environment. Therefore it is necessary to model the sensor suite to be built and its components under different views (e.g. DoDAF, MoDAF) and to have a means to develop a system prototype and a synthetic environment very fast at an early stage of the development process in order to evaluate and validate solution alternatives. Moreover prototypes, models, scenarios, and simulations shall be easily changeable. Therefore, we decided to create executable virtual prototypes in SysML with only a limited set of artifacts, such as use cases, use case diagrams, activity diagrams, sequence diagrams, and block definition diagrams. Figure 5 depicts a structural example of a SAR sensor simulation with its associated synthetic environment and its interacting operator control (OCS), and presentation (PRS) components. Each block has its own methods, attributes, and states which enables compilation, execution and validation of the model in animated sequence diagrams or state charts. After the virtual sensor simulation is validated, the model is integrated in the virtual lab and tested again with already existing models.

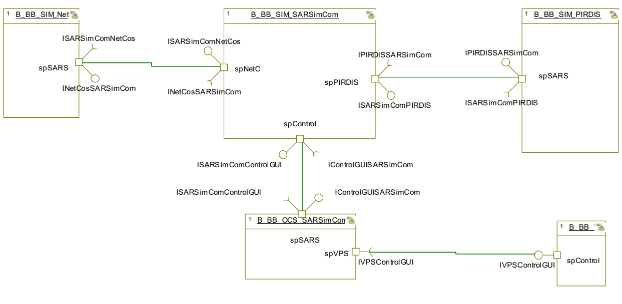


Figure 5: Block Diagram of a SAR Simulation with Synthetic Environment.

We also decided to use COTS products that provide open and standard interfaces for building the synthetic environment, platform simulations, and visualizations. This provides that new components and mathematical models can be integrated and re-used in the virtual sensor suite and its environment by means of a plug-in mechanism. Re-usability of components is also supported by a product structure which splits the lab in re-usable operator control (OCS), presentation (PRS), simulation (SIM), processor (PRC), and infrastructure components (INF), see **Figure 6**. This way it is ensured that new components can easily be incorporated in the product structure, the interfaces will be well defined, scenarios, and simulations can easily be changed and applied at a high level of abstraction. If a scenario reveals that a model does not fit the requirements the virtual prototype can easily be exchanged without changing the interfaces. Due to the executable model-driven approach there is sufficient evidence that the structural integrity of the lab is maintained after the system is integrated.

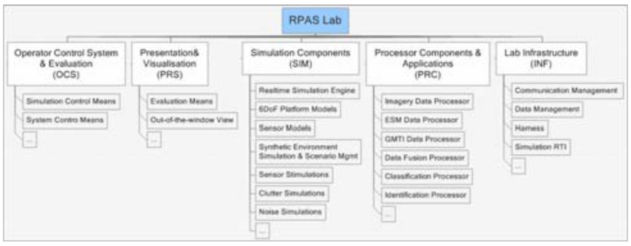


Figure 6: RPAS Structure

3.2. Simulation

The simulation tasks of the sensor suite demonstrator provide realistic models and stimulations. The simulation will demonstrate a target detection, classification and identification with cooperating sensors (SAR/GMTI, EO/IR, ESM) and the necessary correlation and fusion path in order to find an optimized sensor mix with high probability of target identification. Sensor and platform mission execution functions will be model driven implemented.

Such an environment comprises a model of the flight dynamic behaviour of the sensor carrier platform (e.g. a UAV), a model of the sensors, models of the environment such as weather models, tactical models and situations, clutter, electromagnetic noise, etc. The simulation environment is used in different user problem domains. Each problem domain requires particular views of perception on the internal status and a means of control and evaluation of the system under test and the simulations provided by the operator control station including visualisation and presentation. Because instances of the operator control station are reusable, extendable and customizable, the simulation must support these requirements. This shall be realized by standard and open interfaces (e.g. HLA) and a modular structure of the simulation (see **Figure 6**).

3.3. Hardware-in-the-loop

The sensor suite demonstrator is a system which is used to process reconnaissance and surveillance sensor data from own-ship EO, IR, SAR, GMTI and ELS sensors and situational information from external NCW information sources. The system creates intelligent situational awareness and targeting information and allows other information consumers to benefit from own-ship-created information.

Simulated sensors and processing models will be replaced by prototypes of flight capable hardware and software.

This will be performed in an iterative process, which means that dependant from the availability of sensors they will be replaced successively. Sensor modifications and sensor development is performed in parallel with the advantage to have a continuous test and integration environment permanently in place. Also, test conditions and simulation environment has to guarantee that system of systems aspects (interoperability) can be taken under consideration at every development status. Finally the demonstrator consists of EO, IR, SAR, GMTI and ELS sensors a sensor data post processing system and a clear interface to a mission execution processing in order to form a flexible and platform adaptable sensor pay-load for a variety of possible sensor combinations. This approach is illustrated in Figure 7.

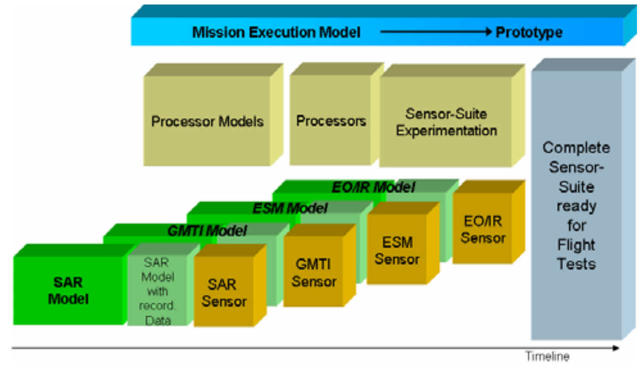


Figure 7: Sensor Sets

Replacement of processor and sensor models by flight capable systems

The core element of the demonstrator is the on-board sensor post-processing with an additional processing unit do merge, correlate and fuse sensor data in order to increase the automated detection, classification and identification capabilities on-board of UAVs and consequently to reduce the amount of information transmission to other platforms and units. This functionality, as indicated in the following Figure 8 will be first developed on processor models and afterwards transferred to a processing unit capable for flight tests.

The on-board sensor post-processing unit receives raw data from the different sensors, performs data reduction and data classification for each sensor and combines and fuse this information in a multi source integration process with additional tactical data receiving from off-board sources. Geo data bases and mission data bases support this process. Additional features are data compression and decompression in order to communicate with off-board sensors.

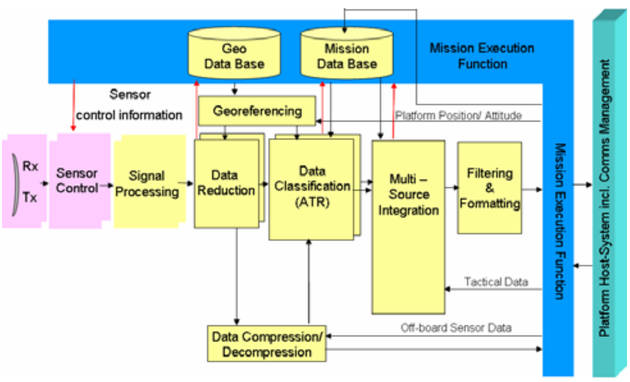


Figure 8: Sensor Suite onboard Post Processing

3.4. Flight Experimentation

Finally a complete sensor-suite with an assessed sensor-mix will be integrated as pay-load for flight test. The platform for flight tests is up to now not defined. Possible candidates are a UAV itself which is under development inside EADS or a manned aircraft (i.e. Tornado) with a realisation in a pod solution as indicated in FIG 3. Under development aspects the pod solution has the advantage that the pod can be an integral part of the prototyping lab and can be tested on ground extensively before going to flight tests. The disadvantage is that the integration in an avionic structure which effects the mission execution functions can only be limited performed.

However, for flight experimentation platform modifications are necessary to adapt the interfaces and to satisfy qualification and certification aspects.

4. CONCLUSIONS

The selection of the best approach for sensor data fusion requires an assessment of alternative technologies to provide a traceable path from system level requirements to technology requirements. The paper presents an EADS methodology using iterative steps which transfers requirements into a system architecture with model based functions, which assesses alternative data fusion concepts by simulation, which replaces simulated sensor functionality by hardware-in-the-loop in order to build up a complete sensor pay-load system and finally which performs flight test experimentation.