Data Fusion for the Finnish Fast Attack Craft Squadron 2000: Concept and Architecture

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Abstract - *This paper describes the concept and the architecture of the scalable multi sensor data fusion system based on an open distributed infrastructure for the new fast attack craft Squadron 2000 of the Finnish Navy. The architecture focuses on the distribution of the data fusion functions into different tasks. This allows an adaptation of the data fusion with minimal cost. The Data Fusion is a hybrid system of plot fusion and track fusion. It contains modern data association and filter methods and has a modular design. For the classification and identification processes within the tactical situation compilation, the Dempster-Shafer method is used. Further the data fusion includes the fusion of remote tracks that are the basis for an extension related to the Cooperative Engagement Capability.*

Keywords: Maritime surveillance, air defence, tracking, filtering, plot fusion, track fusion, sensor integration, situation assessment.

1 Introduction

The European Aeronautic Defence and Space Company (EADS) has developed an Advanced Naval Combat System (ANCS) including a multi sensor data fusion system for the Finnish fast attack craft Squadron 2000 (Hamina class). The ANCS is based on well developed and tested components from the new German Frigate F124 [1] and the ground based air defence system SAMOC [2].

The Squadron 2000 class [3] (see Figure1) will be updated with the new equipment in the summer of 2004 and tested during the winter 2004/2005. Figure 1 shows a Squadron 2000 vessel before the update. The fast attack craft will contain the TRS-3D multi mode radar, the EOST electro optical surveillance and tracking system, a navigation radar, the SIEWS electronic warfare system, the COMS-ESM communication electronic warfare system and the CEROS 200 fire control system. This paper focuses on the realisation of the embedded data fusion concept and architecture.

2 Sensor Suite

This chapter gives an overview of the sensor suite of the Finnish fast attack craft Squadron 2000. The vessel contains a set of active and passive sensors and includes the processing of remote data (Data LINK). All these sensor systems provide data for the Combat Management System.
The active sensors are:

- Multi Mode 3D Radar (TRS-3D)
- Fire Control Radar (CEROS 200)
- Electro Optical Surveillance and Tracking (EOST)
- Identification Friend or Foe (IFF)
- Navigation Radar

Figure 1: Finnish fast attack craft Squadron 2000 (Hamina Class) before the upgrade

The passive sensors are:

- Shipborn Integrated Electronic Warfare System (SIEWS)
- COMmunication Electronic Warfare system (COMS-EW)
- Electro Optical Surveillance and Tracking (EOST)

The TRS-3D is the main sensor. It is a C-band 3D multi mode radar and includes the air and surface surveillance. The coverage range is up to 200 km. The TRS-3D sensor provides sensor point tracks with associated measurements and Doppler data for the ANCS.

The EOST includes active and passive mode. In the active mode the EOST produces sensor point tracks. The range is measured with a laser finder. In the passive mode only the infra-red signature of the target will be measured and therefore the EOST sends sensor bearing tracks to the system.

The IFF produces mode 1, 2, 3a, C, 4 and S plots. This data is corrected with roll, pitch and heading data (electronic stabilisation).

The fire control radar CEROS 200 produces sensor point tracks with high precision data accuracy. For the surface surveillance a navigation radar provides sensor point data.

For the electronic warfare two sensors are available. SIEWS is used to identify active radar and Laser sensors. This sensor produces sensor bearing tracks. The COMS-EW is used to identify communication activities. It sends bearing measurements to the ANCS.

3 Software Architecture

The fast attack craft Squadron 2000 is designed mainly for combat missions as a missile boat [3]. Therefore the Advanced Naval Combat System was adapted to the requirements that have to be fulfilled by this vessel. It integrates all relevant warfare segments for the Squadron 2000 and provides the operational capabilities and performance for effective mission deployment. Further it is able to handle simultaneous operations against a multi-mission threat: anti-air, anti-surface warfare. Besides the handling of local data, the Advanced Naval Combat System has the capability to handle the Finnish navy data LINK and the NATO data LINK (LINK 11 and 16). It is fully reconfigurable and offers the possibility for upgrades within its architecture [4].

Figure 2 shows the structure of the software architecture of the Advanced Naval Combat System. For communication of the system components a Common Object Request Broker Architecture (CORBA) based middleware is used operating with Commercial Off The Shelf (COTS) Hardware. The sensors, the effectors, the Navigation system and the Communication system communicate via a COTS network and the CORBA based middleware with the software components and vice versa.

The Software Architecture is structured into 5 main segments and a subset of the Data Fusion Process Model of the Joint Directors of Laboratories [5]:

- Multi sensor data fusion , Tactical situation compilation and LINK (MTL)
- Threat Evaluation and Weapon Assignment (TEWA)
- Naval Control Command and Planning (NCCP)
- Effector and Sensor Monitoring and Control (ESMC)
- Support Segment

Owing to the modular structure of the Advanced Naval Combat System, major new segments e.g. a segment for mine warfare can be added. All main segments are further subdivided into smaller software components. Also the software components within each main segment have a modular structure. For example in the TEWA segment an electronic warfare component and/or an anti submarine warfare component [4] could be added. Each software component consists of several tasks.

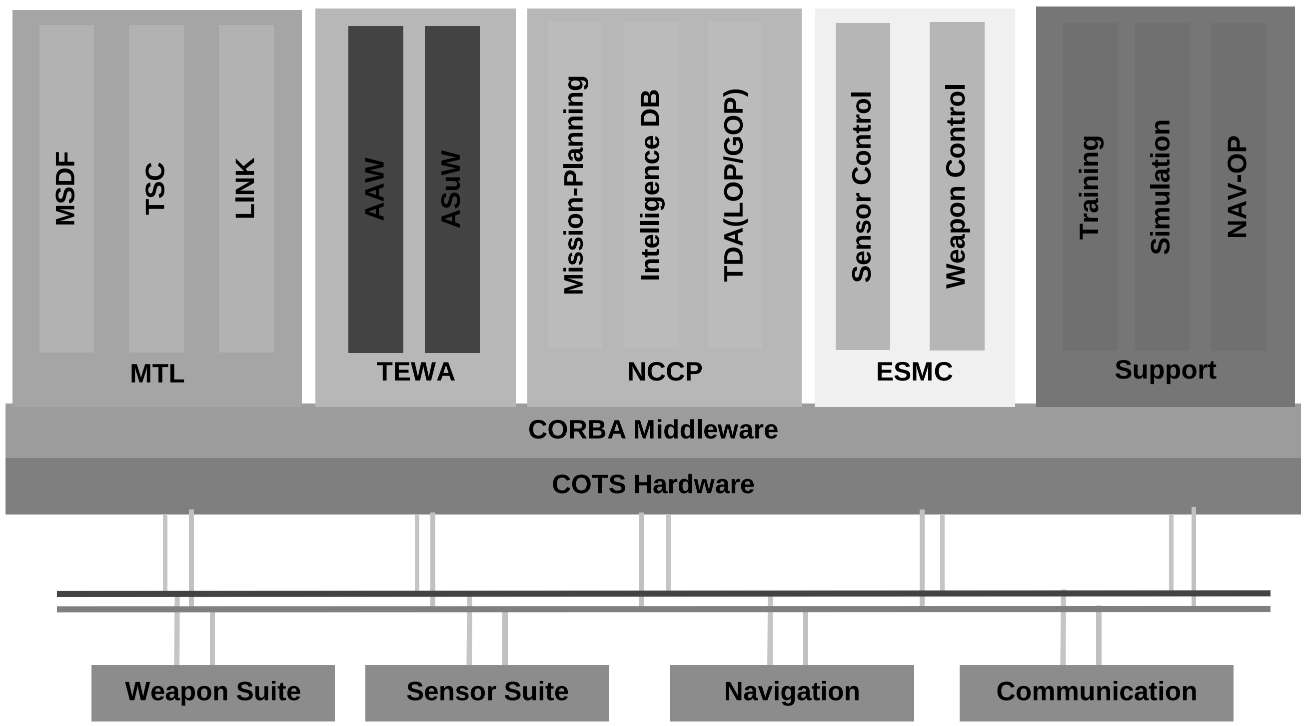

Figure 2: Modular Advanced Naval Combat System Software Architecture

The MTL segment is structured into the software components:

- Multi Sensor Data Fusion (MSDF)
- Tactical Situation Compilation (TSC)
- Data Link System (LINK)

The TEWA segment is structured into the software components:

- own ship Anti Air Warfare (AAW)
- Anti Surface Warfare (ASuW)

For the Squadron 2000, the Anti Air Warfare is optimised for self protection, but the ANCS gives the possibility of extending the Anti Air Warfare software component to a complex force Anti Air Warfare component (see [4]).

The NCCP segment is structured into the software components:

- Mission Planning
- Intelligence data base
- Tactical Display Area (TDA)

The mission planning function is performed by the software component Mission Planning. The software component Intelligence data base contains the library for the intelligence data.

The ANCS data is displayed on the TDA. The non real time data is presented on the General Operations Plot (GOP) and the real time data is presented on the Local Operations Plot (LOP).

The ESMC segment is structured into the software components:

- Effector Monitoring and Control
- Sensor Monitoring and Control

Both segments are used for the monitoring and control of the effectors and sensors by the operator.

The Support segment is structured into the software components:

- Training
- Simulation
- Navigation Operation (NAV-OP)

The software component Training is used to store the input and output data of the ANCS for training purposes. This includes the replay of a stored scenario. The stored data can be real or simulated data. To establish simulated scenarios for training purposes, the software component Simulation is used. The Software component NAV-OP is among other things responsible for route planning, collision detection and the presentation of weather data.

4 Architecture Layer

The ANCS Architecture Layer consists of the COTS Hardware layer, the operating system LINUX and the real time data replication middleware, DONAR (**D**istributed **O**bject **N**otification **A**nd **R**eplication), (see Figure 3).

DONAR forms the standard communication layer of the ANCS software. It provides a publisher/subscriber model of communication where a consumer does not need to know the producer of data and vice versa, thereby decoupling producers and consumers and providing a high level of location transparency.

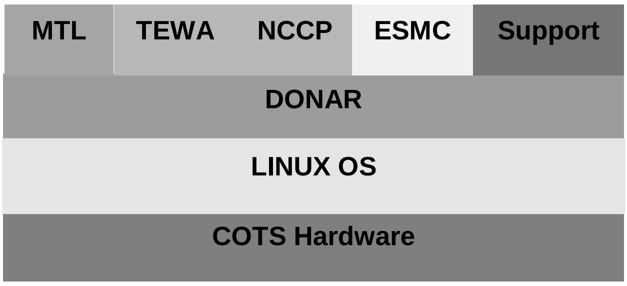

Figure 3: ANCS Architecture Layer

The main part of DONAR is the data replication service that ensures that the data is available and kept simultaneously up-to-date on all possible consumers. For high performance and fault tolerance, a highly efficient replication service is required. The replicated data is available locally on all nodes, thus costly network accesses are avoided. The object replication enhances damage and fault resistance.

DONAR uses CORBA for data transport. It forms a layer on top of CORBA to shield the application processes from the internals of the CORBA communication. Where necessary, CORBA is expanded for efficient data transport, e.g. multicast communication.

For highly-frequent data updates (e.g. sensor track kinematics), the data must be transported with low delay and the reliability of the distribution is of less importance . Other data (e.g. system data) must be transported reliably and should survive a possible crash of its consumers. For this kind of data, DONAR allows a special database-like data storage so that a new process can receive (recover) this data during its (re-)initialisation phase.

Owing to the network communication, the sending sequence of data from a producer and the arrival sequence of data by the consumer may not be the same. Therefore the application software must take into account out of sequence data.

Since the combat management system is based on a standard Unix operating system and operates over a standard 100MBit Ethernet the data transported in the CMS network is of a soft realtime nature. This means that the application software is designed to tolerate data distribution latencies on the order of a few tens of milliseconds. However, performance measurements have shown much smaller average latencies, even in high load scenarios.

5 Data Fusion Application

The Data Fusion of the Advanced Naval Combat System is distributed into four segments:

- Multi Sensor Data Fusion
- Tactical Situation Compilation
- LINK
- TEWA

The following sections describe the functionality of these segments with the main focus on the Multi Sensor

Data Fusion. Figure 4 describes the data flow from local sensor data, operator initiated data and remote data (LINK) into system tracks. For planning the software segment TEWA uses for planning the data from the system tracks.

5.1 Multi Sensor Data Fusion

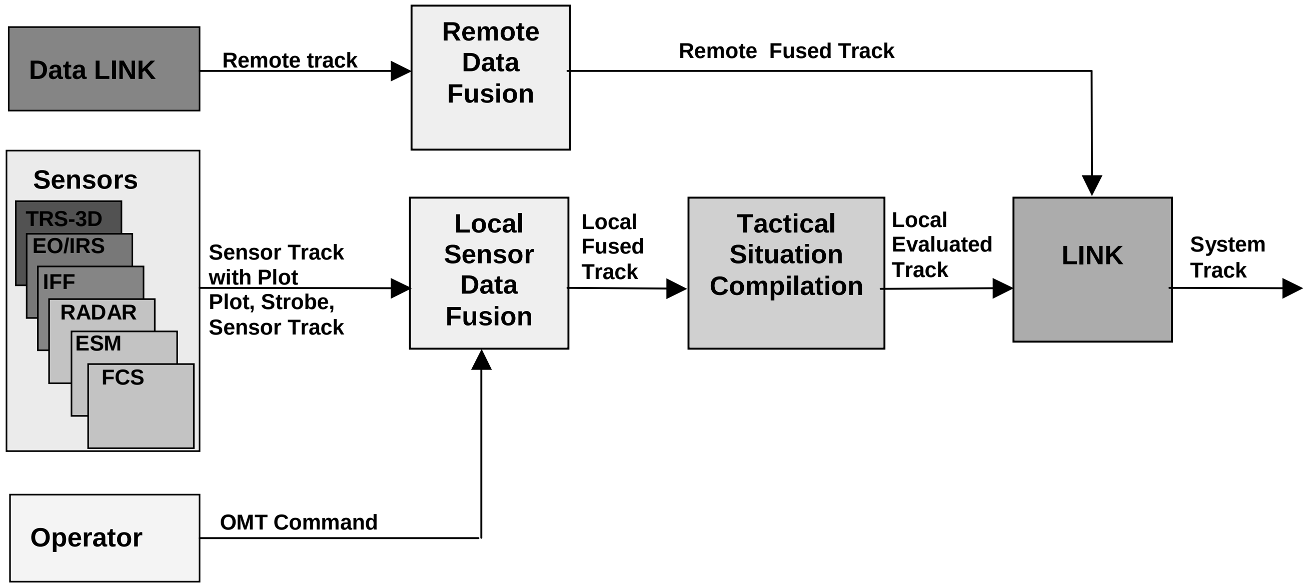

Figure 4: Dataflow from Data LINK, local sensors and operator to the system track

As shown in Figure 4, the Multi Sensor Data Fusion is split into 2 main components, the Local Sensor Data Fusion (LSDF) and the Remote Data Fusion (RDF). The Local Sensor Data Fusion is split into three main tasks which are shown in Figure 5. These are the sensor data fusion task (Fusion), the Operator Maintained Track task (OMT) and the Integrity Maintainer task. The Operator Maintained Track task handles the operator initiated and updated manual local fused tracks. These manual local fused tracks can be fused on operator request with automatic local fused tracks that were initiated on sensor data. The Integrity Maintainer task maps the system command into local commands for the local sensor data fusion and vice versa.

5.1.1 Local Sensor Data Fusion

In the literature there exist two main solutions to establish a data fusion system. These solutions are the central level data fusion (observation fusion) and the decentralised level data fusion system (sensor track fusion). Many investigations were made into using either one of these two solutions [5], [6], [7], [8], [9], [10], [11], [12]. In the first case, the fusion is done only and directly on observations. The advantage of this system is the good fusion and tracking result. The disadvantage is the extremely high data transfer rate. This architecture needs a lot of CPU power for the data fusion system and for the network data transfer. Further the fusion system has to incorporate the clutter handling of each sensor which increases the complexity of the fusion system. In the second case, the fusion is done on sensor tracks. The advantage is the low data transfer rate, use of less CPU power in contrast to the sensor level data fusion and a strongly reduced clutter handling for the sensors. The clutter handling for each sensor is done by the appropriate sensor tracking system. The disadvantage is the worse fusion and tracking quality compared to the central level data fusion system.

A compromise between these two systems is the hybrid fusion system that delivers optimal results considering the content of the sensor data and the sensor data rate [6]. In this case, the sensors provide the sensor tracks with the associated observations. The associated observation is the observation that is used for an update of a correlated sensor track. The fusion and tracking quality is about the same as for the central tracking, but the data transfer rate is not significantly higher than for the decentralised level sensor data fusion system. The clutter handling is the same as in the decentralised data fusion system.

The reality of a sensor suite shows that a clear decision based upon optimal data output is not possible for a fusion system, may it be a central level data fusion system, de-central level data fusion system or hybrid data fusion system. Some sensors provide sensor tracks with associated measurements, some only measurements and other sensors provided only sensor tracks. Therefore, this local sensor data fusion system incorporates the central level data fusion system, the hybrid fusion system and the decentralised level data fusion system (see Figure 5).

The input data from the TRS-3D Radar are sensor point tracks with associated plots. The plot data contains the position and range rate with the corresponding accuracy and non-kinematics data such as helicopter detection flag. The IFF system provides IFF-plots with the IFF-codes, the position and roll, pitch and heading. The FCS and the navigation radar provide only sensor point tracks without associated observations. The EOST sensor provides either sensor point tracks or sensor bearing tracks but both without associated measurements. The input data from SIEWS is sensor bearing tracks without associated observations and strobes are provided by the COMS-EW strobes are provided.

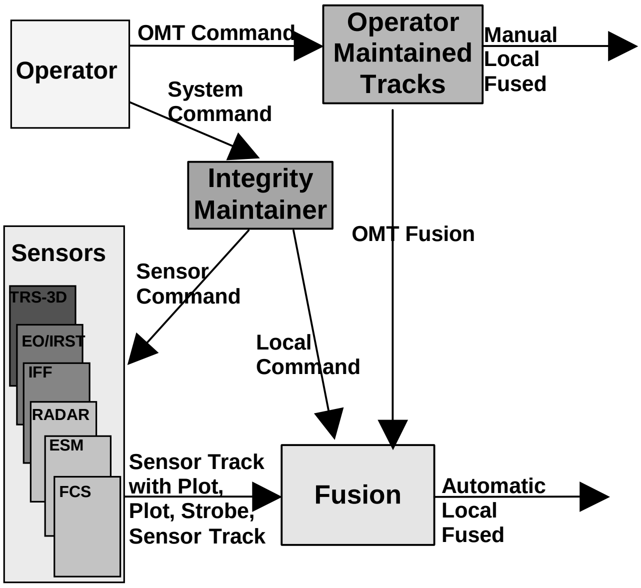

Figure 5: Local Sensor Data Fusion Architecture

The aim of the fusion process is to provide a unique track representation of every object to the relevant Tactical Situation Compilation and further to the operator. This means that all sensor data of one target shall be fused to one local fused track and finally one system track.

A brief view on the radar sensor suite shows that the input data from the sensors differ significantly. On one side there is a rotating passive phased array radar for air and surface surveillance (TRS-3D) and on the other side there is an electro-optical sensor and passive sensors. To fuse this data without a loss of track quality in contrast to the sensor track data, modern data association and filter methods are used [1], [10], [11], [12].

The local sensor data fusion estimates the environment of the local track after the fusion process. This estimation is based on kinematic and non-kinematic data. The algorithm is based on the Dempster-Shafer method [9].

5.1.2 Remote Data Fusion

In contrast to the local sensor data fusion, the data input for the remote data fusion from Data LINK is remote tracks without associated measurements. Further the possible time delay between update data having about the same time of measurement but stem from two different remote tracks for one and the same target is significant larger than for local tracks. Also the update rate is lower, in contrast to the local sensor data fusion. Owing to these facts, the remote data fusion is a decentralised level data fusion system. The algorithms that are used are the same as used in the local sensor data fusion system, but they are optimised with respect to the possible time delay and low update rate of the remote data.

The remote data fusion operates in two modes: Fusion mode and conversion mode. The fusion mode is used if remote tracks are not according to the LINK11 or LINK16 standard. I.e. a target will be supported by two or more remote tracks. In this case, the remote tracks representing one target will be fused into one remote fused track. The conversion mode is used, if the remote tracks fulfil the LINK11 or LINK16 standard i.e. one target is supported by only one remote track. In this case, the remote tracks from the Finnish Navy Data LINK are only converted into the remote fused track.

5.2 Tactical Situation Compilation

The software configuration Tactical Situation Compilation (TSC) supports the operator in the classification and identification process of an object, based on the delivered local fused track data from Local Sensor Data Fusion. This data is both kinematics and non-kinematic (IFF-data e.g. mode 4 data, EW-data e.g. platform data). For the classification and identification of a local fused track, the kinematics and non-kinematic data of a local track are compared with entries in a fully configurable database. This database contains data from the doctrines, the rules and from the operator. The classification process works either in an automatic mode or a manual mode. If in the automatic mode the classification is ambiguous, the operator gets a proposal. If the classification process of a target is not conclusive, an automatic IFF interrogation will be initiated for the target. The identification process can be operated in three modes: the automatic mode, the semi-automatic mode or the manual mode. In the automatic mode, all the data of the target will be used to determine the identification of the target (ID-Fusion). If this determination contains contradictory information, a warning will be raised to give the operator the possibility to resolve this conflict. In the semi-automatic mode, proposals for the identification of a target will be presented to the operator. In the manual mode, no identification will be calculated by the ANCS.

The algorithms used for the classification and identification process are based on the Dempster-Shafer method [8] owing to the reliability of the sensor data. After the classification and identification process, a local fused track is promoted to a local evaluated track and sent to the LINK segment.

5.3 LINK

The LINK segment includes the Finish Navy Data Link, and optional the tactical Data LINK11 and the tactical data LINK16 components. It receives the remote fused tracks from the remote data fusion and the local evaluated track from the Tactical Situation Compilation. LINK correlates the local evaluated tracks with the remote fused tracks. This correlation is based on kinematic and non-kinematic data according to the tactical LINK rules. After the correlation, LINK decides, using operational rules, which kinematic data will be provided to the operator and stored in the system track. Further the operator can manually merge remote fused tracks with local evaluated tracks.

Besides the correlation function, LINK transmits local data via the LINK network in accordance with the LINK rules. The data exchange is supported by the radio transmission and the received function is provided by the Communication.

The establishing of a system point track from a remote received ESM bearing track and a local ESM bearing track is handled within this LINK segment.

5.4 TEWA

The Threat Evaluation and Weapon Assignment functionality plans to counteract attacking targets according to the threat values and the effector resources. This is configurable with doctrines, rules and operator decisions. TEWA uses the system track data (either local or remote data) for creating multiple own ship engagements for multiple threat situations

6 Conclusions

In this paper the concepts and architecture of the data fusion system for Finnish fast attack craft Squadron 2000 are described. The concept and architecture apply distributed CPU power across the local real time network in combination with real time CORBA based middleware.

The data fusion system is split into the following software segments: Multi Sensor Data Fusion, Tactical Situation Compilation, LINK and Threat Evaluation and Weapon Assignment.

The sensor input to the Multi Sensor Data Fusion differs significantly between the sensors. On the one side, the input data is sensor tracks with associated observations or pure observations and on the other side only sensor tracks. Further the sensor suite is not homogeneous. It ranges from a rotating Passive Phased Array Radar (TRS-3D) to a conventional rotating radar system (navigation radar), then to an electro optical system (EOST) and finally to two different Electronic Support Measurements systems (SIEWS, COMS-EW). To handle all this data from the different local sensor and remote systems, a modern data association with modern filter methods was implemented. Further remote tracks originating from a single target are fused to one remote fused track, which will be then correlated with the local tracks in the LINK segment. Due to the modularity of the ANCS, the LINK correlation function can be extended to fully fuse local and remote data. This feature is a basis for the extension of the ANCS with respect to handling the functionality of common engagement capability within the network centric warfare concept.

The Tactical Situation Compilation segment classifies and identifies targets. The classification and identification process operates in an automatic mode or a manual mode. In the automatic mode the classification and identification process is based on kinematic and non-kinematic data and uses the Dempster-Shafer methods. It is fully configurable with doctrines, rules or operator decisions.

The Threat Evaluation and Weapon Assignment segment plans the defence against attacking targets on own ship level. The planning is also configurable via the doctrines, rules and operator decisions.

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