Data Fusion for the new German F124 Frigate

Concept and Architecture

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Abstract - *This paper describes the architecture and implementation of a scalable multi data fusion system based on a distributed database oriented middleware for the new German frigate class SACHSEN. The main operation of this scalable multi sensor data fusion system is air defence. The architecture focuses on the distribution of the data fusion functions into different tasks to allow for the distribution of CPU power. The multi hypothesis tracking system of the Data Fusion is a hybrid system of plot fusion and track fusion. It contains adaptive interactive manoeuvre models with extended Kalman filtering. For the classification and identification processes within the tactical situation analysis the Dempster-Shafer method is used. These concept and architecture have shown a good performance in final tests for the German Navy.*

Keywords: Maritime surveillance, air defence, tracking, filtering, plot fusion, track fusion, sensor integration, situation assessment, sensor management, out-of-sequence data.

1 Introduction

The European Aeronautic Defence and Space Company (EADS) has successfully functional integrated the Combat System with a scalable multi sensor data fusion system for the new German Navy's F 124 class air defence frigate. The development started in 1995.

The First of Class, the Frigate SACHSEN (see Figure1), was delivered to the German procurement department of the BWB at the end of October 2002 and will be handed over to the German Navy in December 2003. Figure 1 shows the Frigate SACHSEN, with sensors during trial runs in Summer 2002 in the North Sea. Currently, the Frigate is under test by the German Navy. This project is a part of the Trilateral Frigate Co-operation Program, which was established by Germany, the Netherlands, and Spain in the early 90s. The Frigate SACHSEN contains the new developed Active Phased Array Radar (APAR) and the newly long range volume search radar SMART-L [1]. It was designed with the main focus on anti air warfare and is the European counterpart to the United States AEGIS Class with the radar system Spy-1. The Frigate CLASS

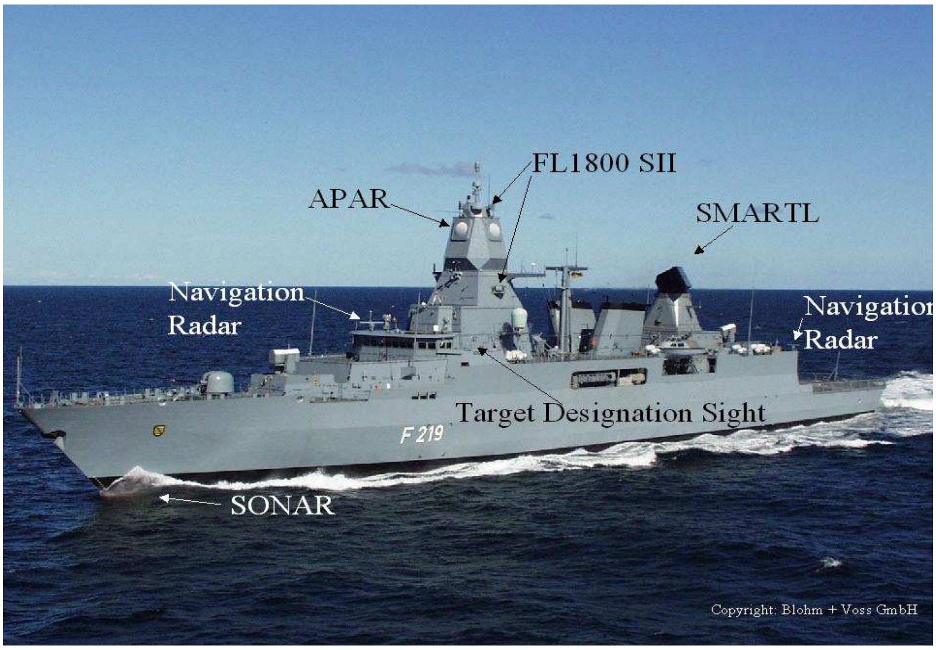

Figure 1: Frigate SACHSEN during trial runs 2002

SACHSEN will replace the German destroyer Class LÜTLJENS, which was build at the end of the 60's. This paper focuses on the realisation of the scalable data fusion concept and architecture.

2 Combat System

The main design focus for the Frigate SACHSEN was to build an Air Defence Frigate for deployed collective security and peacekeeping operations. For the operations centre within the ship, the Combat System is able to handle simultaneous operations against a multi-mission threat: anti-air, anti-surface and anti-submarine warfare. The consoles within the operation central are freely configurable. That means that for example a console can first be used by an air surveillance controller and later by a surface surveillance controller. Further the Frigate SACHSEN is able to guide Missiles without losing information of the tactical and operational area. Beside the local operation, the Combat System can handle the LINK 11 and 16 capability. The Combat System is fully re-configurable and offers the possibility for "upgrades" within its architecture [2].

Figure 2 shows the structure of the Combat System. It is main structured into 8 main segments [2] and a subset of the Data Fusion Process Model of the Joint Directors of Laboratories [3]:

- Anti Air Warfare (AAW)
- Anti Surface Warfare (ASuW)
- Anti Submarine Warfare (ASW)
- Electronic Warfare (EW)
- Combat Direction System (CDS)
- Data LINK System (DLS) with LINK11 and 16
- Navigation (NAV)
- Communications (COMS)

All segments are further subdivided into Hardware Configuration Items (HWCI) and Computer Software Configuration Items (CSCI). The function of the Hardware Configuration Items and the Computer Software Configuration Items of the Anti Air Warfare, Anti Surface Warfare and Anti Submarine Warfare segments are split up into several tasks.

The Anti Air Warfare Segment is structured into the following Hardware Configuration Items and Computer Software Configuration Items.

The Hardware Configuration Items

- Sensors (APAR, SMARTL and IFF)
- Effectors (Vertical Lunch System MK41, Rolling Airframe Missile)

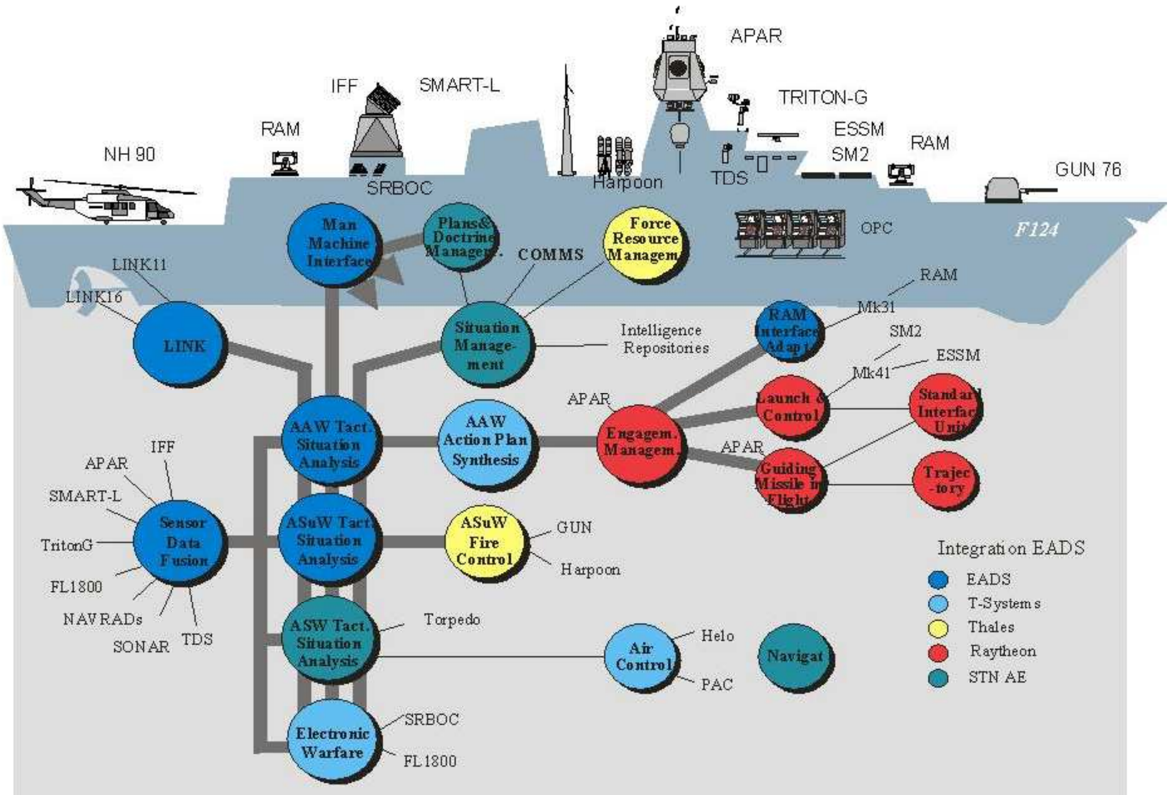

Figure 2: Frigate SACHEN with the Combat Management System

The Computer Software Configuration Items are:

- Sensor Data Fusion (SDF)
- Tactical Situation Analysis for AAW
- Human Machine Interface (HMI)
- Action Plan Synthesis (APS)
- Fire Control (FC)

The Anti Surface Warfare segment is structured into following Hardware Configuration Items and Computer Software Configuration Items.

The Hardware Configuration Items are:

- Sensors (Navigation Radar, Surface Radar, TDS)
- Effectors (HARPOON, Guns)

The Computer Software Configuration Items are:

- Tactical Situation Analysis for ASuW
- Human Machine Interface (HMI)
- Fire Control for ASuW (FC)

The Anti Submarine Warfare segment is structured into the following Hardware Configuration Items and Computer Software Configuration Items.

The Hardware Configuration Items are:

- Sensor (Hull mounted Sonar)
- Effectors (2 triple Torpedo Mk 32)

The Computer Software Configuration Items are:

- Tactical Situation Analysis for ASW_OP
- Human Machine Interface (HMI)

The Combat Management System integrates all warfare segments with their Hardware Configuration Items and Computer Software Configuration Items to provides the operational capabilities and performance for effective mission deployment for the Frigate F124. This Combat Management System is capable of simultaneous operation against a multi-mission threat: anti-air, anti-surface and anti-submarine warfare. Further it can be split up into an operational system and several simulation systems for training at the same time.

The Computer Software Configuration Item of the Sensor Data Fusion is only formally a part of the Anti Air Warfare segment. The input in the Sensor Data Fusion is the information of the incoming local sensor data from the Anti Air Warfare segment, the Anti Surface Warfare segment, the Anti Submarine Warfare segment and the Electronic Warfare (see Figure 2.). The Sensor Data Fusion fuses the sensor data or establishes associations between the sensor data and provide the output of this process to the relevant warfare segments.

3 Hardware/Software Concept

3.1 Sensor Hardware

The following chapter gives an overview of the sensor suite of the new German Anti Air Warfare Frigate Class SACHSEN with APAR and SMARTL in comparison with the and USS Guided Missile Destroyer of the Aegis class (see Table 1).

Table 1 shows the main sensor of the new German Frigate F124 and USS Guided Missile Destroyer of the Aegis class [1], [4], [5].

Function	**F124**	**Aegis**
Air search	APAR SMARTL	AN/SPY-1D E/F band 1
Surface search	APAR, SMARTL	AN/SPS-67(V)3 G-band
Fire control	APAR	AN/SPY-1D E/F band 1 3 x AN/SPG-62 I/J band
Sonar	Bow sonar DSQS-24B.	AN/SQQ-89(V)6 sonar suite

Table 1: Comparison between the F124 Class and the Aegis Class Guided Missile Destroyer [1],[4],[5],

For the air defence capability the I/J-Band Active Phased Array Radar (APAR) [4] was used. The APAR provides the multi-function capabilities required for modern missile threats. This includes following functions simultaneously for the near and middle range.

- Air and Surface Surveillance
- Search Capabilities (e.g. target designation or cued search)
- Multiple Missile Guidance

The complete APAR multi function radar consisting of 4 faces covers 360 degrees. The sea surveillance covers up to 32 km and the air surveillance covers up to 150 km and as well as up to 70° elevation [4].

For the long range surveillance a new D-Band volume search radar (SMARTL) was developed. It is a 3D multi-beam radar providing long range up to 400 km coverage and as well as up to 70° elevation for the air surveillance with 14 beams. This surface surveillance covers up to 60 km. [4]

For the surface surveillance two navigation radar provide data for the Combat Management System. For the submarine observation, a hull-mounted active and passive SONAR system is used. Beside these radar systems and the SONAR system, the sensor suite of the Frigate SACHSEN contains a FL1800 S II Electronic Warfare System, two Target Designation Sights (TDS, starboard and port) and an IFF system MkII Mod 4. All these sensor systems provide data for the Combat Management System [1].

3.2 Middleware

For the local network of the Combat Management System, a data bus with an asynchronous transfer mode is used. The Bus Interface Units and the Multi Function

Consoles are connected to the local real time network. They contain distributed processing resources (Nodes). The Bus Interface Units are used for the physical interface between the sensors and effectors to the local real time network. Each Node contains a number of SPARC/RISC processor boards. This leads to a distribution of the computing power within the Combat Management System. Therefore, the Combat Systems contains not a few CPU's with very strong CPU-power, but the CPU-power is distributed across many of CPU's within the Nodes. A Node has to provide two main tasks. First, to provide a data based oriented interface and communication protocol and second the execution of the embedded application software of the Computed Software Configuration Items [2].

This architecture has among others two advantages:

- The Multi Function Console is freely configurable, that means, that each operator can login with his role at each Multi Function Console .
- Although the embedded applications of the Computer Software Configuration Items are hosted in a specific node, the application may be loaded at start-up in any processors of any node. The application does not know where it is executed. This allows a dynamic reallocation mechanism that can be automatically controlled. That means, if a processor or a Node crashes, the stopped applications will be distributed to the available computing resources and started again. For the reallocation process, non periodical data must be specially stored. This enables a very graceful degradation of the operational ability of the system in the case of hardware failure. If few nodes have hardware failure, the system shows no decrease in performance.

In contrast to the advantages, this architecture has two disadvantages:

- The data based oriented interface and communication protocol in connection with the reallocation support needs a lot of computer power.
- Owing to the local 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 the out of sequence data.

4 Data Fusion Application

The Data Fusion of the Combat System is distributed into four functional groups:

- Sensor Data Fusion
- Tactical Situation Analysis for the Anti Air Warfare, the Surface Warfare and the Submarine Warfare
- LINK
- Action Plan Synthesis

The following sections describe the functionality of these functional groups with the main focus on the kinematics data fusion (Sensor Data Fusion)

4.1 Sensor Data Fusion

The three main tasks of the Computer Software Configuration Item of the Sensor Data Fusion are described in Figure 3. These are the data fusion (Fusion),

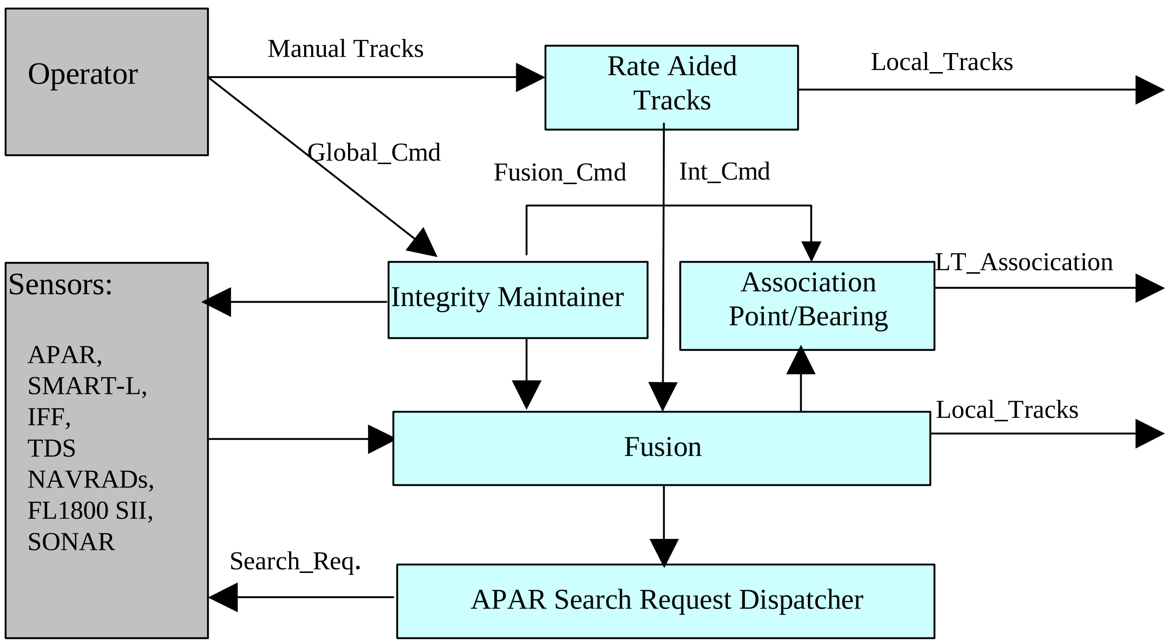

Figure 3: Tasks of Sensor Data Fusion

the association between a radar point track and one or more bearing tracks (Association Point/Bearing) and the sensor management (APAR Search Request Dispatcher) for the Active Phased Array Radar. Two further minor functions are described in Figure 3. The Integrity Maintainer task handles the operator commands for the sensor data fusion. The other task is the Rate Aided Track task. which handles the operator initiated manual tracks. These tracks can be fused with other local tracks within the sensor data fusion on operator request.

4.1.1 Fusion

Many investigations were made into using a central level data fusion system (observation fusion) or a decentralised level data fusion system (sensor track fusion) [3], [6], [7], [8]. In the first case, the fusion is done only on observations. The advantage of this system is the good fusion and tracking result. The disadvantage is, that the data transfer rate is extremely high and therefore this system cannot be used in an actual real time system. In the second case, the fusion is done on sensor tracks. The advantage is the low data transfer rate, but the disadvantage is the worse fusion and tracking result compared to the central level data fusion system.

A compromise between these two systems is the hybrid fusion system that delivers the 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 are used for an update of the sensor track. The fusion and tracking result is about the same as for the central tracking, but the data transfer rate is not significantly higher than the data transfer rate for the decentralised level sensor data fusion system. Besides technical theoretical considering, the real world has to be considered. It is because not all sensors provide sensor tracks with associated observations and one sensor provides only observations.

Therefore, for the Sensor Data Fusion, a combined system was developed. It incorporated the central level data fusion system, the hybrid fusion system and the decentralised level data fusion system (see Figure 4).

The Figure 4 shows the input data from the sensors of the different warfare segments and the local tracks and the APAR Search Requests, the output of the Sensor Data Fusion.

The input data from the Anti Air Warfare sensors SMARTL and APAR is sensor tracks with associated plots. The plot data contains the position and range rate with the corresponding accuracy and non-kinematics data like helicopter detection. The IFF system provides IFF-plots with the IFF-codes, the position and role and pitch.

The input data from sensors of the Anti Surface Warfare and Anti Submarine Warfare is only sensor tracks without associated observations.

Additional to these input data, the Figure 4 shows quick

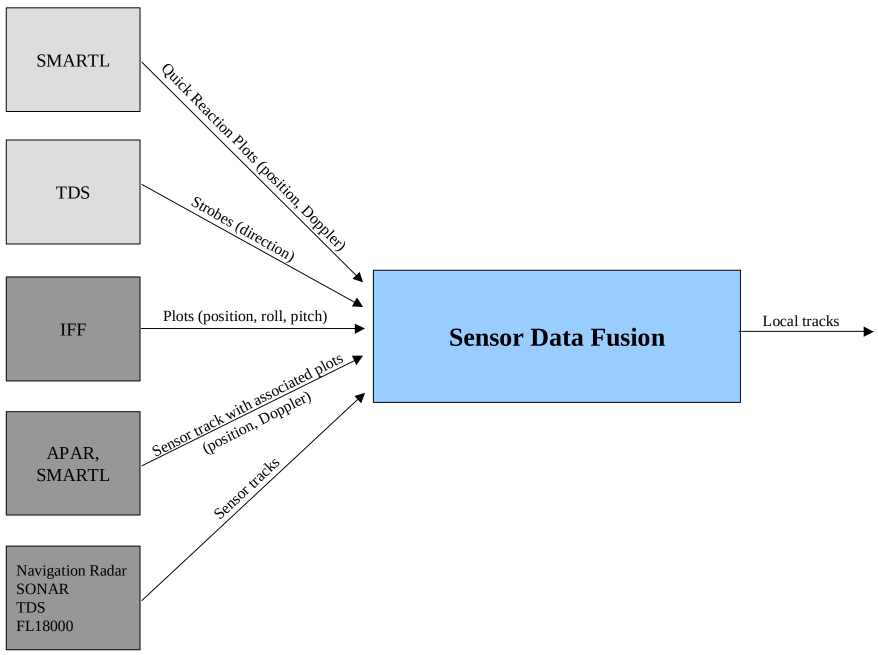

Figure 4: Input data of the Sensor Data Fusion

reaction plots and Target Designation Sight strobes. These data are used for the sensor management of APAR.

The aim of the fusion process is to provide a unique track representation of every object to the relevant Tactical Situation Analysis and operator. This means that all sensor data of one target shall be fused to one local track. But according to the tactical LINK rules, the bearing data are transferred over the LINK network and therefore they shall not be fused to local tracks. Nevertheless, each sensor bearing track is converted to a local track without a fusion with other sensor data.

A short view on the radar sensor suite shows that the input data from the sensors differ significantly. On the one side there is a rotating Passive Phase Array Radar for the long range surveillance (SMARTL) and on the other side there is an Active Phase Array Radar. To track these data within the fusion process and without a loss of the track quality in contrast to the sensor track data, the following algorithms are used:

- Multi Hypothesis Tracks [9]
- Adaptive Interactive Manoeuvre Models [10]
- Extended Kalman filtering [11]

In the Multi Hypothesis Tracking a hybrid association scheme is used. This means that the track-plot associations provided by the sensor trackers are preserved. But all operations to check the association of the sensor track with a local track are based on the associated plot if one is available (otherwise the sensor track kinematics are used). This results in the fact that an association has only to be made in the case of a new sensor-track or when the kinematical update gives reason for it (e.g. split or dense target situations, or inconsistent associations of the sensor trackers in case of crossing weaving targets with multiple fused sensors).

For the Adaptive Interactive Manoeuvre Models three manoeuvre models are used. These are one constant-velocity filter and two coordinate turn filters with an adaptive turn-rate [12]. In addition an active height detection is made. This models are needed to fit the requirements for course and speed with all type of targets (e.g. airliners, missiles, popup-dive manoeuvres or surface targets).

The Sensor Data Fusion estimates the environment (such like subsurface, surface, air or land) of the local track during the fusion process. This estimation is based on kinematics and non-kinematics data. The algorithm is based on the Dempster-Shafer method [9].

4.1.2 Association

The aim of the sensor data fusion is to integrate all sensor data of one object to one track. But as described above, the sensor bearing tracks are not fused with other sensor data, owing to the tactical LINK rules. To provide the system with information, that one or more bearing tracks are related to one point track, the Sensor Data Fusion contains a special process, the so-called Association Point/Bearing process. The associations are also provided to the relevant Tactical Situation Analysis, and operator.

4.1.3 Target Designation and Cued Search

In general, not all objects in the Combat Management System, that are based on local data, are tracked by APAR. If the Sensor Data Fusion gets sensor track data of a target from sensors other then APAR and APAR does not actually track this target, the Sensor Data Fusion analyse these data for the threat. If the analysis shows that the threat is above a given threshold, the Sensor Data Fusion initiates a target search request to APAR. A target designation request based on the sensor track data. Figure 4 shows also quick reaction plots from SMARTL and strobes from the Target Designation Sight. The quick reaction plots are automatically produced by SMARTL and analysed within the Sensor Data Fusion for the threat value. If the threat value is above a given threshold a cued search request is send to APAR. In contrast to the automatically handling of the cued search request for quick reaction plots from SMARTL, the strobes from the Target Designation Sight are operator maintained. For each incoming strobe the Sensor Data Fusion initiates a cued search request to APAR. All cued search requests are based single observations (plot or strobe).

Besides the given threat values for the initiation of a target designation request or a cued search request, sensor data fusion analyses the load of APAR. This is done to prevent APAR being overloaded by to much search requests. Furthermore, the operator can switch on or off this functionality within the Sensor Data Fusion.

4.2 Tactical Situation Analysis

The Computer Software Configuration Item of the Tactical Situation analysis is separated into the three environment categories: Air, Surface/Land and Submarine.

Each Tactical Situation Analysis supports the operator in the classification and identification process of an object based on the delivered local track data from Sensor Data Fusion. This data is both kinematics data and non-kinematics data (e.g. platform data). Within the classification and identification process associations between the local tracks are considered. For the classification and identification of a local track, the kinematics data and non-kinematics data of a local track are compared with entries in a database. This database is fully configurable. It contains data from the doctrine manager and from the operator. If the results of the classification and identification process of a target is not sufficient, an automatic IFF interrogation will be initiated for the target. The algorithms used for the classification and identification process are based on the Dempster-Shafer method [9] owing to the reliability of the data from the sensors. After the classification and identification process, a local track is switched to a system track. This system track is provided to the LINK.

Based on the system track a threat evaluation by calculation of a threat index will be done. The threat will be provided to the operator and to Action Plan Synthesis for further engagement calculations.

4.3 LINK

The Computer Software Configuration Item of the LINK includes the tactical Data LINK11 and tactical data LINK16 components. It receives and distributes the tactical information in a closed and defined group of users on co-operation platforms. The data exchange is supported by the radio transmission and the received function is provided by the COMMS.

Further the LINK correlates the local system tracks with the remote tracks, received via the COMMS: This correlation is based on kinematics data and non-kinematics data according the tactical LINK rules. After the correlation, LINK decides using operational rules, which kinematics data will be provided to the operator, the local system track or the remote track.

4.4 Action Plan Synthesis

The Computer Software Configuration Item of the Action Plan Synthesis plans to combat attacking targets according to the threat values and the effector resources. This is configurable with the doctrine manager. Action Plan Synthesis operates either on the force level or the own ship level. At the own ship level, the Action Plan Synthesis creates multiple own ship engagement for multiple threat situations. At the force level, the exploration of the available weapons within the task force will be used for the engagement planning.

5 Conclusions

In this paper the concepts and architecture on the scalable multi sensor data fusion system for the new German Frigate Class SACHSEN are describe. The concept and architecture apply distributed CPU power across the local real time network in combination with a real time database oriented middleware.

The scalable multi sensor data fusion system is split into Computer Software Configuration Items: Sensor Data Fusion, Tactical Situation Analysis for the Anti Air Warfare, Anti Surface Warfare and Submarine Warfare and the Action Plan Synthesis.

The sensor input of the Sensor Data Fusion differs significantly between sensors. On the one side, the input data are 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 with an Active Phased Array Radar (APAR) to over an rotating Passive Phased Array Radar (SMARTL), then to conventional rotating radar systems, electro optical systems (Target Designation Sight) and an acoustic System (active and passive SONAR systems) and finally to an Electronic Warfare System (FL1800 SII). To handle all this data from the different sensor systems, a Multi Hypothesis Tracking system with Adaptive Interactive Manoeuvre Models and Extended Kalman filtering was implemented. Owing to the tactical LINK rules, only the point track data are fused. The bearing tracks are associated with the corresponding point tracks.

Beside the tracking functions, the Sensor Data Fusion contains the sensor management for APAR. This sensor management decides based upon data from other sensor systems, whether a target search request or a cued search request will be initiated to APAR or not. The target designation request based on sensor tracks and the cued search request bases on single observations.

The Tactical Situation Analysis classifies and identifies the targets. The classification and identification process is based on kinematics data and non-kinematics data and uses the Dempster-Shafer methods. It is fully configurable with a Doctrine Manager or an operator.

The Action Plan Synthesis plans the defence against the attacking targets either on the force level or the own ship level. The planning is also configurable via the Doctrine Manager or the operator.

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