Joint-FACET: The Canada-Netherlands Initiative to Study Multi-Sensor Data Fusion Systems

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ABSTRACT

This paper presents the progress of a collaborative effort between Canada and The Netherlands in analysing multi-sensor data fusion systems, e.g. for potential application to their respective frigates. In view of the overlapping interest in studying and comparing applicability and performance of advanced state-of-the-art Multi-Sensor Data Fusion (MSDF) techniques, the two research establishments involved have decided to join their efforts in the development of MSDF testbeds. This resulted in the so-called Joint-FACET (Fusion Algorithms & Concepts Exploration Testbed), a highly modular and flexible series of applications that is capable of processing both real and synthetic input data. Joint-FACET allows the user to create and edit test scenarios with multiple ships, sensors and targets, generate realistic sensor outputs, and to process these outputs with a variety of MSDF algorithms. These MSDF algorithms can also be tested using typical experimental data collected during live military exercises.

KEYWORDS: sensor fusion, simulation and testbeds, multiple target tracking

1. INTRODUCTION

Major ongoing activities undertaken by the Decision Technology Section at Defence Research Establishment Valcartier (DREV) and the Observation Systems Division at TNO Physics and Electronics Laboratory (TNO-FEL) are the investigation of sensor management, integration, and Multi-Sensor Data Fusion (MSDF) techniques that could apply to the current Canadian and Dutch Frigates Above Water Warfare (AWW) sensor suite, as well as their possible future upgrades, in order to improve their performance against the predicted future threats. Fundamental issues in developing an MSDF system are the selection of an appropriate architecture and the choice of efficient and dedicated fusion algorithms to fulfill its role in the ship combat direction system.

The increasing tempo and diversity of open-ocean and littoral scenarios, and the volume and imperfect nature of the data to be processed under time-critical conditions, threats characterized by high speeds, low approach altitudes or steep dive trajectories, maneuverability, and the ability to deceive defensive systems using countermeasures pose significant challenges to future shipboard Command and Control Systems (CCSs) and the operators who must use these systems to defend their ship and fulfill their mission. The littoral environment is particularly stressful. The presence of dense, commercial air traffic and merchant shipping challenges the operators in distinguishing between hostile, neutral, and friendly tracks. The proximity to hostile shores decreases the available battlespace and warning time and makes it possible to use land-based Electronic Counter-Measures (ECM) and increases clutter levels; this offers more vulnerability against land-based missile attacks. Furthermore, weapon developers recognize the vulnerabilities of the defensive systems and develop or evolve weapons in an attempt to defeat them. As the threat becomes more sophisticated, additional aids to the operators will be increasingly required. The crew is bombarded with sensor and link information which must be correlated, fused and interpreted in order to arrive at some understanding of the tactical situation. Automation has emerged as a possible option to assist the operators in coping with the ever-increasing flow and complexity of information, in their task of tracking and identifying multiple targets.

Fundamental issues in developing an MSDF system are the selection of an appropriate architecture and the choice of efficient and dedicated fusion algorithms to fulfill its role in the ship combat direction system. By joining their efforts, Canada and the Netherlands are mutually increasing their capability to explore a wider range of design philosophies, as well as the opportunity to benefit from the participants' previous experiences and lessons learned. The approach retained for this joint effort is to employ sufficiently representative sensor and phenomenological simulations in the development of a MSDF

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testbed. As funding becomes more constrained, the conduct of costly at-sea trials is likely to be reduced, and simulations are becoming more and more important in the development and testing of MSDF systems. However, an essential part of the simulations is to check the models with known test cases in order to establish confidence in the results. Often, the costs are driven beyond the intended scope of the project by running superfluous cases that become evident after running just a few sets. With a careful planning, a judicious selection of a representative set of test cases can be made in order to conduct only the required trials.

A highly modular and flexible testbed is being developed as the result of the evolution of two existing testbeds: the DREV CASE_ATTI[1] (Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification) and the TNO-FEL MT3[2] (Multiple Target Tracking Testbed). The resulting higher capacity testbed is hereafter referenced as Joint-FACET (Fusion Algorithms & Concepts Exploration Testbed). Joint-FACET will be used by Canada and the Netherlands in analyzing the various performance trade-offs required in the selection of the best multi-sensor data fusion architecture and algorithms applicable to their respective frigates. Joint-FACET is an open-loop simulation, i.e., the tactical picture is obtained without feedback from human operators.

This paper describes Joint-FACET and identifies specific collaborative projects that need to be carried out to pursue its development. The paper is organized as follows. A generic MSDF system is described in Section 2, followed in Sections 3 and 4 by a description of the CASE_ATTI and MT3 testbeds. Finally, the Joint-FACET is presented in Section 5.

2. A GENERIC MSDF SYSTEM

Figure 1 shows a generic MSDF system where the key functions are identified. A detailed description of all these functions is provided in Ref. 3. The processing can be divided into blocks such as: 1) data alignment (spatial, time); 2) data association; 3) target kinematics data fusion; 4) target identity data fusion; 5) track management process; 6) cluster management process; 7) input data preparation; 8) track database; 9) fusion configuration monitoring and control.

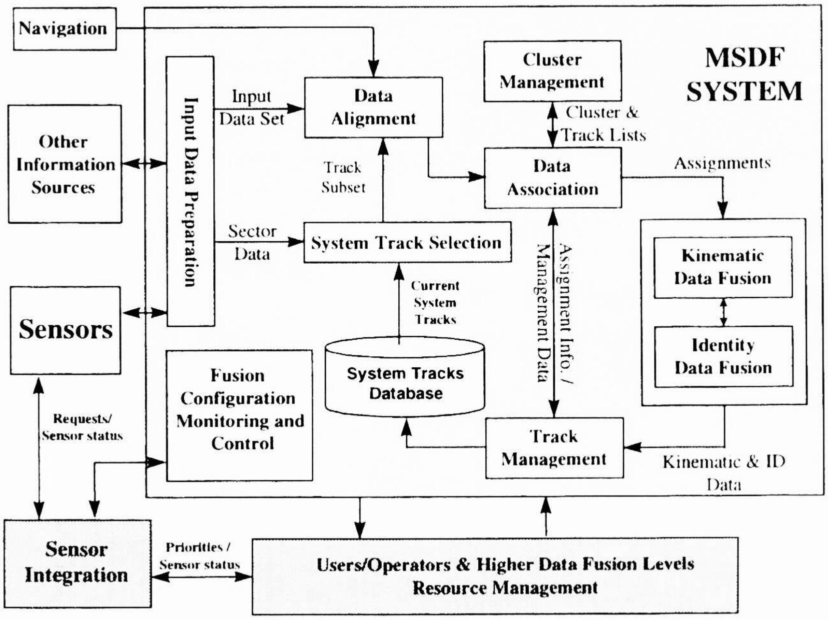

FIGURE 1 - A generic MSDF system

In any MSDF system, a sensor data alignment in time and space must take place before any fusion can be performed. Navigation data are used to estimate and remove the effects of platform motion from the received data. The functions of data association (labeling measurements from different origins and/or sensors, at different times, that correspond to the same object or feature) and data fusion (combining measurements from different times and/or different sensors) are also required in one form or another in essentially all multiple sensor fusion applications: data association determines what information should be fused, the fusion function performs the fusion.

In addition to the MSDF system which detects, localizes, and identifies targets, the sensor integration, on the basis of an evolving picture, and under the command of the overall Command and Control (C2) resource management, manages the information that the MSDF might receive by pointing, focusing, maneuvering, and adaptively selecting the modalities of its sensors and sensor platforms. The overall C2 resource management has the responsibility of first examining and prioritizing what is unknown in the context of the situation and threat and then developing options for collecting this information by sending priorities to the sensor integration function.

One of the key issues in developing an MSDF system is the question where in the data flow the data is to be fused or combined. The MSDF architecture is an important issue since the benefits[4] are different depending on the way the sensor or other source data are combined. There are four broad alternatives to fusing positional information: at the signal level, at the contact (plot) level, at the track level and finally a hybrid approach which allows fusion of either contact or track data. For identity fusion, there are several types of architectures which can be used: 1) data level fusion, 2) feature level fusion, and 3) decision level fusion. There is no universal architecture which is applicable to all situations or applications. The selection of the MSDF architecture type should be aimed at optimizing the target detection, tracking and identification performance required for a specific platform given its missions. However, the selection is also constrained by the technological capabilities (both hardware and software). It depends on the quality of the sensors being fused, the availability of computer processing power, the bandwidth of the available data transmission paths, and the degree to which operator intervention is required or desired.

3. THE CANADIAN CASE_ATTI TESTBED

An ongoing activity undertaken by the Data Fusion Group in the Decision Support Technologies Section at DREV is the investigation of sensor management, integration, and Multi-Sensor Data Fusion (MSDF) concepts that could apply to the current Canadian Patrol Frigate (CPF) Above Water Warfare (AWW) sensor suite, as well as its possible future upgrades, in order to improve its performance against the predicted future threat. The approach retained for this activity is to employ sufficiently representative sensor and phenomenological simulations. Hence, to achieve this exploration, a testbed has been developed. This testbed, called CASE_ATTI, provides the algorithm-level test and replacement capability required to study and compare the applicability and performance of advanced, state-of-the-art MSDF techniques.

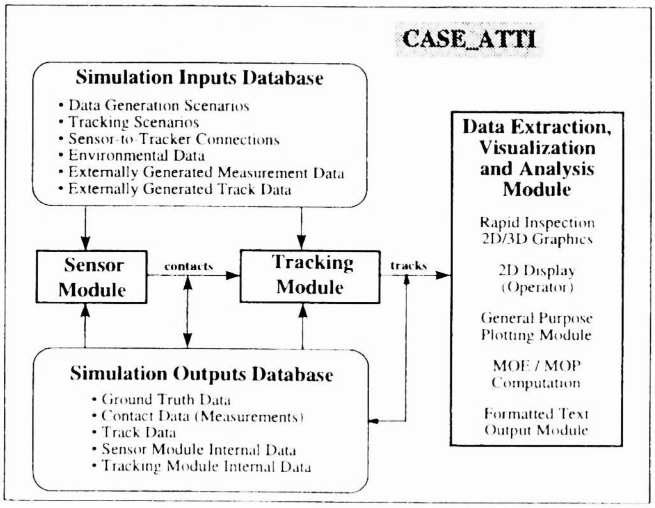

FIGURE 2 - The global structure of CASE_ATTI

The CASE_ATTI system allows the user to create and edit test scenarios with multiple ships/sensors/targets. The ships can be stationary or moving along predefined paths. One or several sensors can be assigned to each ship. Targets are created with defined trajectories and attributes. The object-oriented design allows the users to easily develop and incorporate their own tracking algorithms, sensor models, and analysis tools. Figure 2 illustrates the global structure of the CASE_ATTI testbed. Three components can be distinguished:

1. Sensor Module

   The sensor module is responsible for providing the realistic measurement data to the tracking algorithms. Given a user-defined scenario, it generates true target positions and measured target positions, which are subsequently made available to the tracking module. Currently, the module supports surveillance radar, IFF, ESM and IR sensor simulations.

2. Tracking Module

   The current tracking module supports a wide variety of tracker architecture types, varying from a simple single sensor tracker to an arbitrary complex hierarchical multiple sensor topology such as the example illustrated in Figure 3. Its design has the capability of simulating a sensor-level, central-level or hybrid MSDF architecture as required. The sensor-level trackers currently implemented include:

   i. Multiple-Hypothesis Tracker (MHT)
   ii. Track-Split filter
   iii. Nearest-Neighbor type trackers (both Munkres-based and optimal)
   iv. (Joint) Probabilistic Data Association filter (JPDA/PDA).

   The MHT implementation is capable of handling reports from multiple sensors; the other trackers handle reports from a single sensor only. A global track fuser using a version of the MHT tracker for assignment has also been provided to fuse the sensor-level tracks to form global tracks. In addition, feedback of these global tracks to the local sensor-level trackers is allowed. Current efforts include provisions for advanced track management schemes such as a Hough-Transform based track initiator tracker, and support for configurations including both active and passive sensors.

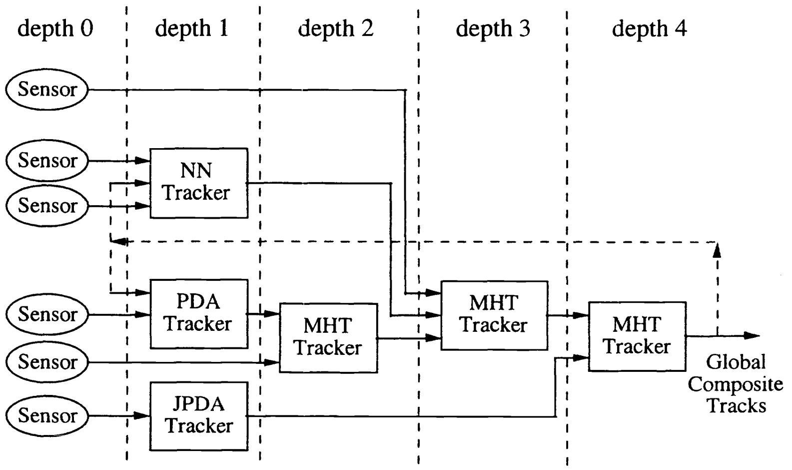

FIGURE 3 - CASE_ATTI generalized tracker (with feedback)

3. The Data Extraction, Visualization and Analysis Module

This module comprises a set of computer tools implemented in CASE_ATTI to help the MSDF designer in his assessment of the performance of the algorithms and techniques.

4. THE DUTCH MT3 TESTBED

At TNO-FEL the Multi-Target Tracking Testbed (MT3)[2] has been developed since early 1996 to support research in the field of tracking and sensor fusion. Currently, the phrase MT3 refers to a series of computer applications that are relevant to assess performance of tracking algorithms utilizing both recorded ('live') data and synthetically generated data. Figure 4 depicts the structure of the MT3. The components are:

1. Sensor Module

   Given a geographical database and descriptions of radars and targets with their trajectories, synthetic plots are produced.

2. Tracking Module (TM)

   This module receives radar plots and performs multi-target tracking. This results in track messages. Originally, the tracking module main requirement was to perform sensor fusion on track and contact levels. At this instant, the tracking module is able to process data that originate from tracking radars (i.e., systems that are capable to aim their antenna at the target of interest) and it can be used to track features in a sequence of optical images.

3. Display Module

   The module receives plot and track messages from the TM and maintains a graphical display. The DM can also be utilized in an unconnected mode in which it reads plots and/or tracks from files.

4. Evaluation Module

   Tracks are compared with the 'ground truth' and performance measures are determined.

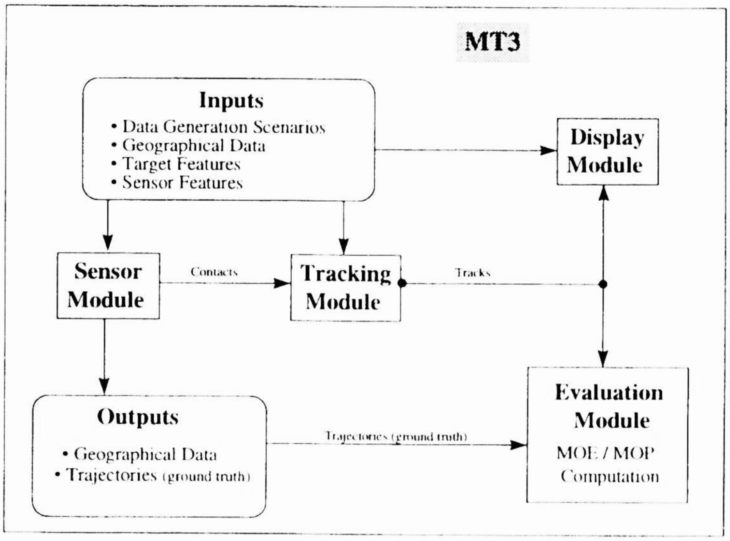

FIGURE 4 - The various components of the Dutch MT3.

Other characteristics are:

- 2D and 3D Kalman track filters.
- Spherical and Cartesian system state description.
- Extended Kalman filter.
- Interacting Multiple Models.
- Bayesian and possibilistic classification of both contacts and tracks.
- Nearest-neighbour plot-track association with preference of plot-track pairs with identical classification.

Near future expansions are:

- Multiple Hypothesis Testing plot-track association.
- Image fusion.
- Sensor fusion on track and contact levels.

The MT3 testbed has been implemented on a UNIX platform (Sun, Solaris 2.5) in C and C++, using in-house developed graphics based on X-windows. Recently, the tracking module has been made available for the Matlab environment.

5. THE JOINT-FACET PROJECT

The primary objective of both the CASE_ATTI and MT3 testbeds is to measure the ability of various MSDF systems to generate the estimated tactical picture that accurately reproduces the ground truth tactical picture. In fact, MSDF is part of an approach (Figure 5) to help counter the anticipated threat to our surface ships by increasing the AWW defence capability through the development of a real-time advisory decision support system (DSS) that supports the tactical decision making and action execution processes in a ship's Operations Room. More specifically, this DSS would: continuously take in data from the ship's sensors and other information sources; form and dynamically maintain an accurate AWW tactical picture (MSDF), and thereby provide the most likely interpretation of the tactical situation; formulate strategies and plans for responding to anticipated or actual threats the overall resource management aspects.

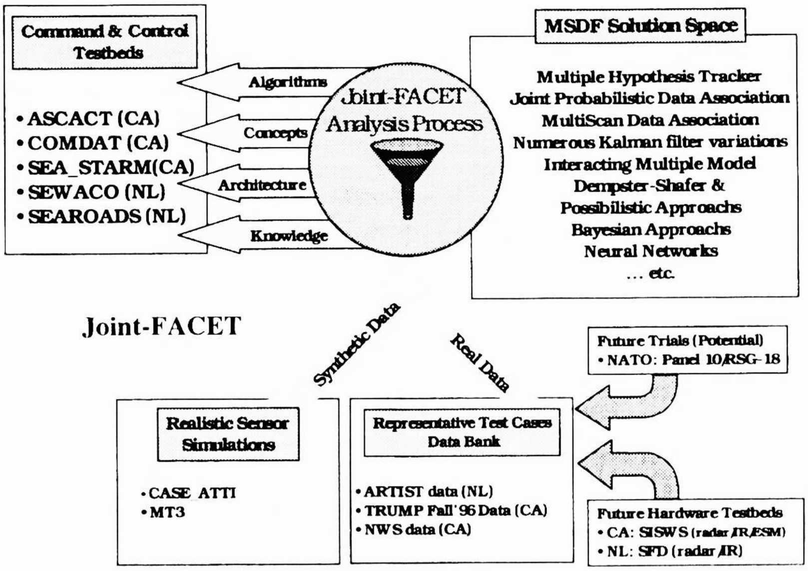

FIGURE 5 - The Joint-FACET approach

DREV and TNO-FEL are currently investigating a diverse range of concepts for designing and evaluating real-time DSS. Several closed-loop testbeds, see Figure 5 (ASCACT, SEA_STARM, etc.), have been or are being built to capture the functional requirements, temporal behaviour and real-time performance of such systems. As open-loop application, Joint-FACET is developed to enlarge the solution space for evaluating concepts, algorithms and architectures for the MSDF aspects only. To some extent, Joint-FACET may be used to address some of the issues related to the local sensor management, but it cannot fully address the MSDF integration with the higher data fusion and resource management levels.

The fundamental issues in developing an MSDF system are the selection of an appropriate architecture and the choice of efficient and dedicated fusion algorithms to fulfil its role in the DSS. The approach retained for that joint effort is to employ sufficiently representative sensor and phenomenological simulations combined with judicious selection of representative data collected during well-controlled experiments. The Joint-FACET analysis process shall scan the MSDF solution space to identify the most promising MSDF algorithms, architectures, concepts or knowledge that are worth being ported to the existing higher level command and control testbeds.

In summary, the primary objective of Joint-FACET is to increase insight in MSDF performance without significant redirection of the CASE_ATTI and MT3. Of course, for the development of Joint-FACET, the objectives of CASE_ATTI and MT3 are still valid. The modular, structured and flexible simulation environments of CASE_ATTI and MT3 make possible their interoperability. The high-level requirements of Joint-FACET are:

- the development shall be pursued independently at physically remote locations without necessarily sharing the same code and platforms;
- each version (Canadian and Dutch) shall have the capability to run the same scenarios and process the same test cases;
- common results evaluation tools shall be developed;
- each version shall have the capability to compare the performance of an algorithm running at one site with respect to a different algorithm running independently at the other site working on the same set of data.

5.1 The Joint-FACET Testbed

Figure 6 shows the global structure of Joint-FACET. It contains the MSDF modules of CASE_ATTI and MT3 where commonality is achieved at critical points in the testbed. A **S**cenario and **D**ata **G**eneration (**SDG**) module will replace the current two sensor modules. Furthermore, a common **P**erformance **E**valuation (**PE**) module will be developed.

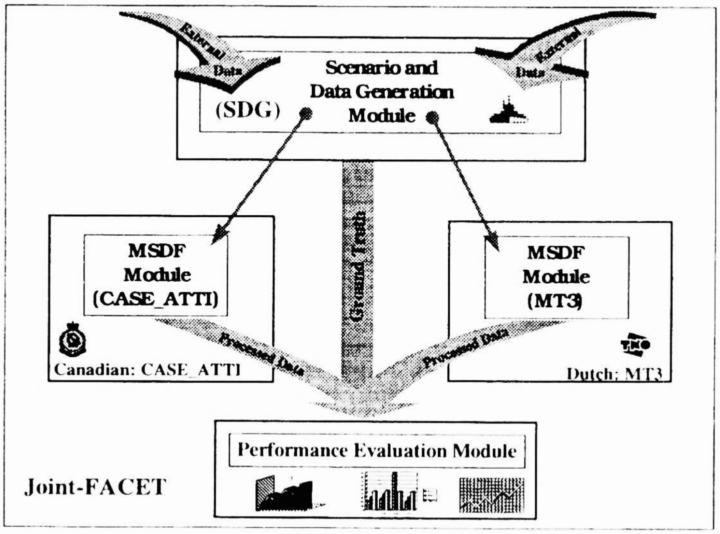

FIGURE 6 - Global structure of the Joint-FACET system

The MSDF modules are the main parts of CASE_ATTI and MT3. A large amount of software currently exists to implement these MSDF modules with quite complementary algorithms residing in both testbeds. The most efficient design is to build from these two main parts without spending efforts in recoding or redesigning a joint module. Hence, the proposed approach shown in Figure 6 is a way to build a joint testbed by proceeding with the recoverable MSDF modules and progressively implement the required commonality in the SDG and PE modules. Some modifications to the existing CASE_ATTI sensor and result analysis modules as well to the MT3 sensor and evaluation modules will have to be made to tailor them for the joint operation.

5.1.1 The Scenario and Data Generation (SDG) Module

The **SDG** module, shown in Figure 7, is responsible for providing the realistic measurement data as well as for communicating externally generated data from other testbeds or experimental systems to the MSDF modules of Joint-FACET. This module allows the user to create and edit test scenarios with multiple ships/sensors/targets. The ships can be stationary or moving along predefined paths. One or several sensors (potentially dissimilar such as radar, infrared, ESM, etc.) can be assigned to each ship. Targets are created with defined trajectories and attributes. The scenario also allows for the selection of environmental conditions (rain, sea state, land, etc.) that may affect the sensor performance. The approach adopted here is to employ sufficiently representative and flexible sensor simulations to make it possible to integrate the latest findings with regard to the dominant perturbing effects which affect the sensor detection performance and measurement accuracy. The SDG module is then used to generate false and true measurements to build realistic synthetic test cases for the MSDF module.

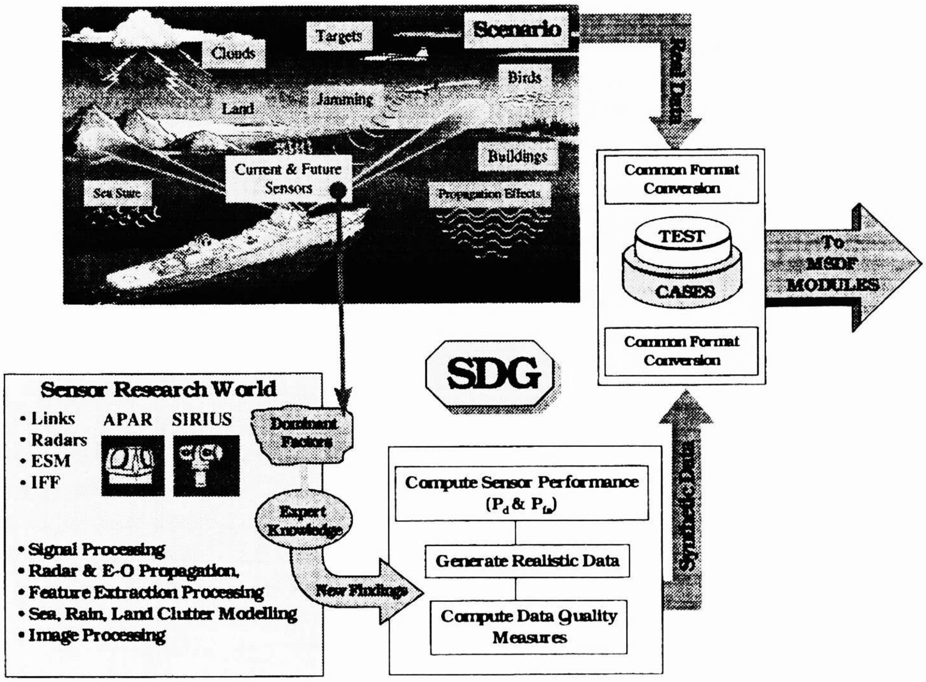

FIGURE 7 - The Sensor and Data Generation (SDG) module

Currently the SDG supports the following simulations:

- Maritime surveillance radars
- Electronic support measurement
- Interrogation friend or foe

Further extensions are required to support:

- Multi-Function Radar
- Infrared search and track
- Fire-control radar
- Link-11 capabilities
- Imaging sensors feature extraction capabilities

The SDG module is also responsible for selecting and preparing (common format) the experimental test cases for the MSDF module. An essential part of Joint-FACET is to check the MSDF concepts, architecture and algorithms with known test cases in order to establish confidence in the results. Trials have already been conducted by both countries. This resulted in a valuable collection of experimental data suitable to MSDF studies. Among them are the ARTIST and TRUMP data. However, we feel more trials need to be conducted to increase our experimental test cases data bank in order to become representative for MSDF studies.

5.1.2 The MultiSensor Data Fusion (MSDF) modules

The current **MSDF** modules (Dutch and Canadian versions) support a wide variety of tracker architecture types, varying from a simple single sensor tracker to an arbitrary complex hierarchical multiple sensor topology. This was described in Sections 3 and 4 and in Refs. 1-2.

5.1.3 The Performance Evaluation (PE) module

The PE module of Joint-FACET is being developed to assess the performance of the MSDF algorithms. Unfortunately, no widely accepted scheme for characterizing the performance of MSDF systems is currently in use. While much research is being performed to develop and apply new MSDF algorithms and techniques, little work has been carried out to determine how well such methods work or to compare alternative methods against a common problem.

Figure 8 illustrates the main elements of the MSDF performance evaluation concept. The ground truth picture represents the real composition and status of a scenario of tactical interest. During its operation, the overall system generates both a measured tactical picture (i.e., the output of the sensing process) and an estimated picture. The purpose of the performance evaluation process is to measure the ability of the MSDF system to generate the estimated tactical picture that accurately reproduce the ground truth tactical picture. The evaluation objective is to quantify the potential divergence that may result from the various limitation factors affecting the performance of MSDF systems.

The type of Measures Of Performance (MOP) considered here are those that measure how well an MSDF algorithm is performing against tactically crucial parameters (localization radial miss distance, for example). Practicality dictates that several different MOPs should be defined to cover several aspects of performance at a time. The MSDF algorithms are typically very complex, highly integrated algorithms whose different parts interact with each other in highly nonlinear and unpredictable ways. As a result, it is entirely possible (and in fact not unusual) that one aspect of performance, as measured by one specific MOP, can be improved only at the cost of decreasing some other aspect. Unfortunately, it is also possible that the aspect of performance which has been decreased will go undetected by the existing suite of MOPs.

For the sake of Joint-FACET, a finite set of MOPs is considered in order to highlight the following three major aspects of performance: reaction time; track quality; identification accuracy.

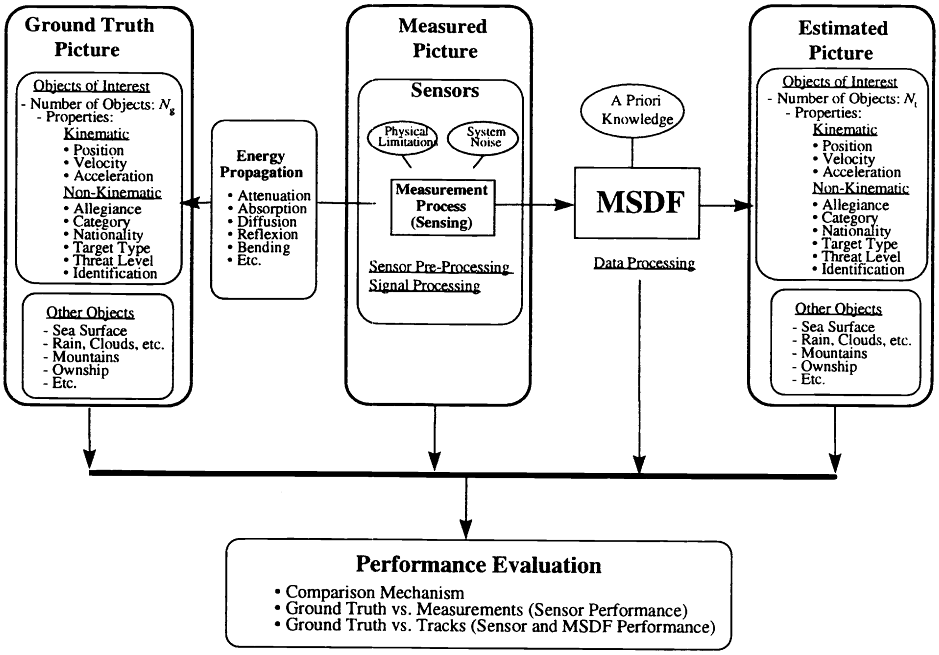

FIGURE 8 - The MSDF performance evaluation concept

6. CONCLUSION

This paper described a collaborative effort between Canada and the Netherlands in analyzing MSDF systems, for potential applications to their respective frigates. In view of the overlapping interest in studying and comparing the applicability and performance of advanced state-of-the-art MSDF techniques, the two research establishments involved have decided to join their efforts in the development of MSDF testbeds. This resulted in the Joint-FACET, a highly modular and flexible series of applications that is capable of processing both real and synthetic input data. By joining their efforts, Canada and the Netherlands are mutually increasing their potential for exploring a wider range of design philosophies, as well as the opportunity to benefit from the participants' previous experiences and lessons learned.

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