Testbed Architecture for Fusion of Imaging and Non-Imaging Airborne Sensors*

Pierre VALIN, Langis GAGNON, Maciej MACIESZCZAK , Elisa SHAHBAZIAN
Lockheed Martin Canada Inc., 6111 Royalmount Ave., Montréal, Québec, H4P 1K6, Canada
tel: (514) 340-8310, extensions 8703, 8715, 8482, 8343
pierre.valin@lmco.com, langis.gagnon@lmco.com, maciej.macieszczak@lmco.com, elisa.shahbazian@lmco.com

Eloi BOSSE,
Defence Research Establishment Valcartier (DREV)
2459 Pie XI Blvd. North, Val-Bélair, Québec, G3J 1X5, Canada
tel: (418) 844-4478, eloi.bosse@drev.dnd.ca

ABSTRACT

This paper describes an on-going effort to build an Adaptable Data Fusion Testbed (ADFT) based on a Knowledge-Based System (KBS) BlackBoard (BB) architecture to perform data fusion of imaging and non-imaging sensors present on-board the CP-140 Canadian maritime patrol aircraft. The algorithms incorporate state-of-the-art tracking in clutter and evidential reasoning for target identification. The end result offers the user a flexible and modular environment providing capability for: (a) addition of user defined sensor simulation models and fusion algorithms; (b) integration with existing models and algorithms; and (c) evaluation of performance to derive requirement specifications and help in the design phase towards fielding a real Data Fusion (DF) system.

REQUIREMENTS

The Adaptable Data Fusion Testbed (ADFT) is designed to accommodate modular interchangeable algorithm implementation and performance evaluation of: (1) Fusion of positional data from imaging and non-imaging sensors; (2) Fusion of attribute information obtained from imaging and non-imaging sensors and other sources such as communication systems, satellites, etc.; and (3) Object Recognition (OR) in imaging data. The design allows algorithms for sensor simulators and measures of performance to reside either on the KBS BB shell or be separate from it, thus facilitating integration with other testbed designs. This architecture also allows the future introduction of Data Fusion (DF) management capabilities.

The ADFT architecture must process the data coming from non-imaging and imaging sensors as typically present on airborne platforms performing maritime surveillance. The non-imaging sensors are a 2-D radar, an Electronic Support Measures (ESM), an Identification Friend of Foe (IFF) and a datalink (Link-11) both for the *planned* Aurora Life Extension Program (ALEP) and the Maritime Helicopter Project (MHP) which will replace the ageing Sea Kings. The imaging sensors present on the Aurora are the Forward Looking Infra-Red (FLIR) and Synthetic Aperture Radar (SAR) which can operate in Strip Map, Range Doppler Profiling (RDP) and Spotlight modes (Adaptive or Non-Adaptive). The attribute data that these sensors can provide is important in determining the identification of target platforms, particularly the long range features that the Spotlight SAR (SpotSAR) can furnish.

GENERIC FUSION MODELS

Humans go through a decision making process described as the "Observe-Orient-Decide-Act" (OODA) loop. In the "Observe" phase of this loop detections are made and analyzed to derive specific characteristic information or data, in the "Orient" phase this information is analyzed with all the contextual information involving the observations to interpret its possible meanings, based on which the most appropriate decision is selected in the "Decide" phase, followed by actions in the "Act" phase.

The OODA model is applicable to human cognition as well as to most scientific and engineering applications. Examples of such applications are: (1) medical diagnostics; (2) remote sensing; (3) robotics; (4) command and control systems for defence, surveillance and search and rescue vessels; (5) control systems for large plants (factories, power stations, etc.); (6) air traffic control; (7) communication networks; (8) security systems; etc. Over the last 15-20 years, DF technology was identified as the domain providing techniques, methods and algorithms for increasing the decision making performance in such applications through integration, analysis and automation of information processing within them. At the outset, DF research was mainly theoretical as the computer technology could not

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support its processing demands, but with advancements in computer technology, DF technology applications in real systems have become feasible, however not yet mature enough to be the core of any major productized system. This technology provides various intelligent decision aid techniques, methods, algorithms for:

a) integrating information from multiple sources and using the complementarity of these detections to derive maximum information about the phenomenon being observed (Level 1 DF),

b) analyzing and deriving the meaning of these observations (Level 2 DF),

c) selecting the best course of action (Level 3 DF), and

d) controlling the actions (Level 4 DF).

ADFT ARCHITECTURE

The real-time Knowledge-Based System (KBS) based on a BlackBoard (BB) shell, which was developed by Lockheed Martin Canada and Defense Research Establishment Valcartier (DREV), is the basis of the ADFT infrastructure. This system is totally generic, and could be used to implement any system comprising of components which can be numeric or AI based. It has been implemented in *C++* rather than in a higher-level language (such as LISP, Smalltalk, ...) to satisfy the real-time requirement. The KBS BB shell provides a unique software architecture which will permit integration and independent evolution, enhancement and optimization of various decision aid capabilities within a system. This architecture was developed as the generic skeleton for the integrated Naval Command, Control, Communication, Computer and Intelligence (C^4I) System for the Canadian Patrol Frigate (CPF) future upgrades at all DF levels [1]. The choice of this specific KBS architecture was made to satisfy a number of requirements such as:

- support both numeric and Artificial Intelligence (AI) techniques,
- real-time efficiency,
- distributed (multiprocessor) environment,
- design flexibility, and

guaranteed real-time execution for decision aid components

This real-time KBS supports distributed processing and permits incremental developments and enhancements of all system components, including the input data simulation for a selected data fusion implementation, as well as each DF component independently. Such systems have been used in the past, although not in real time, for computer vision, planning and scheduling, data fusion or command and control systems. In such a BB environment, knowledge is generally encapsulated in the form of sets of procedures or production rules (if-then statements) or as semantic nets that describe a network of objects and their relationships, through inheritance. Our KBS BB architecture supports the capabilities of a generic BB system, where the knowledge sources (or agents) containing algorithms, contextual facts, logical rules or heuristics are activated as a result of a data structure appearing in the BB or by another agent. They contribute pieces of information by modifying some control or data structure on the BB. BB systems offer highly structured opportunistic problem solving strategies, whether it be data-driven or goal-driven.

One very unique characteristic of our KBS BB architecture is that it can grow indefinitely, without affecting the previous developments and without having to re-compile and re-link the whole system. The KBS Shell is an executable and the User Libraries include all generic agents (e.g. system control and monitoring). These stay unchanged, while the user can add and link its functions (data structures, rules and agents) on top of these incrementally as shown in Fig.1. Considering the flexibility of the KBS BB architecture, different components residing in this environment need not all be integrated at the same time to ensure testbed functionality. For the airborne surveillance application the simulated sensors, the image analysis, image enhancement, and feature extraction algorithms and the fusion algorithms can be developed and integrated on KBS incrementally. It has been decided to evolve the airborne surveillance application in incremental phases, first re-using an existing data fusion functions and demonstrating the integration of the testbed based on this architecture, and then incrementally separating the data fusion algorithms and the rest of the testbed components into agents on the blackboard, permitting the independent evolution of these algorithms and the other components. In the last phase all additional algorithms from other projects and the infrastructure permitting the addition of user-defined algorithms will be incorporated.

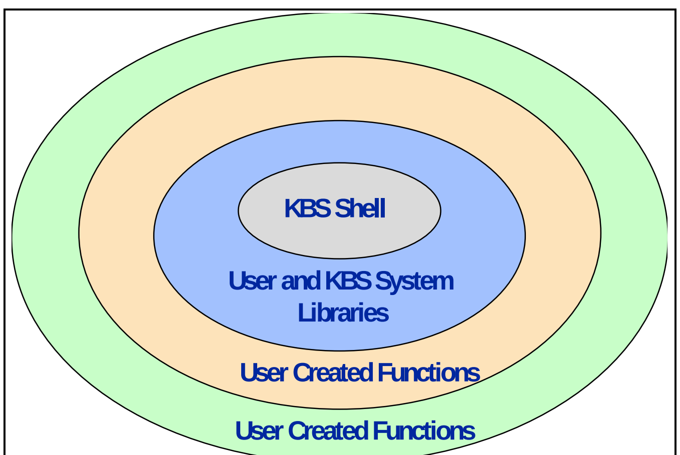

Figure 1 - KBS BB Internal Structure

AIRBORNE SURVEILLANCE APPLICATION

The DF Level 1 system tailored for airborne surveillance envisioned for the ADFT will use the sensor suite of Canada's CP-140 Aurora aircraft (mentioned in the Requirements Section and shown in Fig. 2) as its baseline configuration, but will be generic enough to demonstrate fusion of any sensor suite that comprises surveillance radars, communications data (datalinks) as well as imaging and non-imaging sensors. As such, it could also be adapted to other platforms, and for different purposes, without any major modifications.

For the airborne surveillance application the following capabilities are required of the ADFT [2]:

(1) Fusion of positional data from imaging and non-imaging sensors,

(2) Fusion of attribute information obtained from imaging and non-imaging sensors and other sources such as communication systems, satellites, etc., and

(3) Object Recognition (OR) in imaging data.

The same type of capabilities are necessary for many other applications such as remote sensing, medical imaging, robotics, air traffic control, etc.. The advantage of starting from the airborne surveillance application is the fact that an initial set of DF algorithms, sensor simulation and scenario generation have been developed as part of previous projects[1-9], and an initial integration of the workstation can be achieved in a relatively short time.

Any generic DF application must contain the following set of sequential functions to act on real or simulated data:

1. *registration* to first perform spatial and temporal alignment of the simulated sensor data,

2. an *association* mechanism to then correlate the new incoming data with possible existing tracks found in the BB database and to send associated positional data to positional fusion and associated attribute data (e.g. image features of a given target) to information fusion,

3. *positional estimation* to then update the tracks in the time domain with the associated new data and write this positional information to the BB database, possibly extracting attribute data such as speed, acceleration and sending to information fusion, and

4. *identification estimation* (or information fusion) to then fuse all attribute data through evidential reasoning, whether they originate from imaging (through image understanding and feature extraction) or non-imaging sensors and consequently update the dynamic BB track database.

As stated above, the ADFT is being build incrementally. In the first phase the KBS BB is simply used as a track database for the fusion processes, which have been developed as part of previous projects. The intent is to demonstrate the ADFT infrastructure integration. Two future phases are envisioned: in the first phase, the DF algorithms are moved on the BB

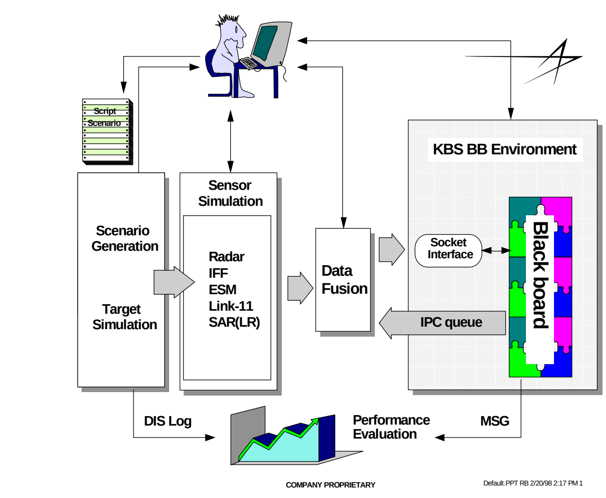

Figure 2 - ADFT airborne application - Phase 1

based KBS and in the second phase, the sensor simulators are also migrated to the BB. This would correspond to moving successively the respective two boxes depicted in Fig. 2 unto the KBS BB environment.

The control flow for the fusion of information is data driven directly from the simulators. The algorithms used within the DF function include: Jonker-Vogenant-Castanon (JVC) algorithm which is an optimal single-scan associator for the *association* function. Three parallel Kalman filters for the *positional estimation* function, and LM Canada developed Truncated Dempster-Shafer algorithm for the *identification (ID) estimation* function. The positional estimation function uses radar, IFF, ESM and Link-11 data and ID estimation uses IFF, ESM, Link-11 and imaging features. In this phase, the only imaging information used by the DF function are long range features from SAR such as ship length. In the first phase, these algorithms are all integrated into one DF function and it is not straightforward to use them for any other application. The first phase is currently complete and the second phase is in progress.

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