Abstract - Future US Air Force sensor systems must be able to adapt to changing environments in real time. A capabilities-based modeling approach is a new method being promoted for the building of the next generation weapon systems. To accommodate this modeling approach the Department of Defense (DoD) is promoting the use of waveform diversity for radar systems. Building a weapon system including one or more radar systems with waveform diversity will require the use of artificial intelligence (AI) tools and techniques. This paper investigates leveraging the AI tools being developed by the Semantic Web, DARPA’s DAML program and, specifically, the building of ontologies and resource description framework (RDF) for sensor systems so that they can efficiently communicate and share their data.

1. Introduction

The Quadrennial Defense Review 9/30/01 states: “The new defense strategy is built around the concept of shifting to a ‘capabilities-based’ approach to defense...A capabilities-based model - one that focuses more on how an adversary might fight than who the adversary might be and where a war might occur - broadens the strategic perspective.” The DoD has always had a capabilities-based philosophy in developing weapon systems. They assessed their capabilities, projected what an enemy’s capabilities would be and developed new or improved weapon systems that would provide the superiority to defeat the capabilities of adversaries. The DoD knows that the enemy is difficult to define [1].

“...the subject matter for most military analysts is far more fluid than during the cold war, rendering standard databases and analytical models for explaining behavior obsolete. Indications and Warning, the analysis which warns of impending attack on the United States or its vital interests, depends on the ability to predict enemy activity, based on enemy plans, doctrine, and observed exercises and training. Many of today’s potential adversaries offer little in the way of traditionally observable activity.[1]”

The enemy is not a single nation with borders that fights like any of our past adversaries. To win battles, the military must be able to confront adversaries in many locations with battle lines that are difficult to define, either on the Earth or in cyberspace. They must be adaptable, quick, innovative, and intelligent in the use of all weapons and information. We measure the time to assess the enemy and plan for the next battle in hours and days, not years. The military can change both the features of some weapons systems and how they deploy them to meet today’s military demands, e.g. unmanned air vehicles. However, other systems will take longer to modify, such as our radar and communications systems. Future US Air Force sensor systems must be able to adapt to changing environments in real time to defeat a highly unpredictable enemy.

This paper addresses an approach for building next-generation sensor systems. Section 2 provides a background on intelligent software development for radar systems. Section 3 describes an intelligent sensor system architecture. Section 4 provides an overview of ontologies and provides an abstract model of an ontology for an intelligent sensor system. The last section provides a summary and future work.

2. Background

Current signal processing systems are built assuming Gaussian clutter and are optimized for processing requirements whether the systems are mounted on an aircraft, a missile, a spacecraft, or at a ground based site. The algorithms are “hardwired” into the computer’s architecture in order to meet the real-time requirements demanded by the sensor’s operating parameters, e.g. scans per second and number of sensor elements. This approach to building radar systems is being assessed today by the radar research and development community because of its rigidity and high costs. It is predicted that this approach will change and evolve. This evolution will manifest itself such that different algorithms and/or their parameters will be modified by the radar’s software as the environment changes. For instance, if a radar is
being jammed by a transmitter from a particular direction, then that radar could place a null in its antenna pattern in the direction of the jammer to reduce its negative effect. This and many more sophisticated algorithms have been studied and numerous research papers have been written.

Some of the most progressive work in employing artificial intelligence (AI) techniques has been pursued by the US Air Force Research Laboratory’s Sensors Directorate. Some of their original efforts have been in the constant false alarm rate (CFAR) portion of a radar’s signal processing chain. Work was performed [2, 3] to demonstrate that if the cell under test is near the boundary of two different clutter regions, then blindly applying a CFAR algorithm (like cell averaging) will not perform as well as choosing only those cells with the same type of clutter as the test cell and then performing cell averaging. This approach provides a better probability of detection and lower false alarm rates. However, to apply this approach for a radar looking for targets whose background is the Earth, requires that the registration of each cell on the earth be known and the type of clutter be categorized to determine which cells are the same type. If the radar is resident on a moving platform looking at the Earth then the algorithm must be dynamic in order to register the radar’s beam on the Earth for each coherent processing interval (CPI). Laboratory experiments with radar data have shown good results especially when a radar is illuminating heterogeneous clutter such as a land sea interface.

This work was extended beyond the detection stage to the rest of a radar’s processing chain under a US Air Force (USAF) effort dealing with knowledge based space time adaptive processing (KBSTAP) [4, 5]. This effort demonstrated the benefits of using outside data sources to affect the filtering, detection, and tracking stages of a surveillance radar. Data from a side looking airborne radar system was used in demonstrating the performance enhancements over a conventional radar. The measurements were obtained from the multi-channel airborne radar measurement (MCARM) program [6] conducted by the USAF. Another program showed the benefits of using map data obtained from the US Geological Survey (USGS) to improve the performance of space-time adaptive processing (STAP) on an airborne radar selecting range rings based on computed criteria rather than blindly choosing the range rings surrounding the test range ring. This effort, KBMapSTAP [7, 8], along with numerous researchers have laid the ground work for a new DARPA program. The Knowledge-Aided Sensor Signal Processing Expert Reasoning (KASSPER) program is to investigate the use of outside data sources to dynamically change a radar’s signal processing chain to enhance a radar’s performance.

Can we build new radar systems that can dynamically change its processing given information from other sensors, outside sources, weather data, etc.? We believe that we can. The computing clock rates for computers have been doubling approximately every 18 months. Today’s commercial off the shelf computers have clock rates exceeding 3 GHz. We believe that the computing power is available to insert sophisticated “rules/logic” within radar signal and data processing.

We need a new approach for building our next generation systems not only for a single radar system but also a platform of sensors. We need to envision our sensors not as stove pipe systems but a system of sensors, whether they are mounted on one platform or multiple platforms. Waveform diversity is that technology that will allow one or more sensors onboard a platform to automatically change its operating parameters, e.g. frequency, gain pattern, pulse repetition frequency (PRF), etc. This will allow the system of sensors to fuse information and allow a sensor to change its operation to meet the stressing and changing environments that our military systems must face and meet the intent of a capabilities-based approach. The reader is referred to a companion paper in these proceedings [9] which provides more explanation of waveform diversity.

3. An Intelligent Sensor System

If an airborne radar is going to share and receive information from multiple sources then it must be able to communicate and understand the information. A solution for the exchange of information between heterogeneous sensors is for each sensor to publish information based upon an agreed and understood format (i.e. an ontology). In this manner when a sensor publishes its track data multiple sensors receiving this information will be able to interpret its contents without ambiguity. Accomplishing this will require that certain basics be established. We must have an accepted method of defining the Earth’s geometry such that every element on the Earth, air or space’s positions are all defined within the same coordinate system. That each element is time synchronized with the same clock and all communications are time stamped.

Each transmission of information between sensors must depict its time and its coordinates. In addition if it is sharing track or target data it must specify their unique identifier, the sensor platform’s velocity, pitch, yaw, and role and meta data describing the transmitted raw data along with encryption/decryption keys. The unique identifier will allow the receiving sensor to acquire, within its resident database management system (DBMS), all of the sender’s radar characteristics. Sensor characteristics include such things as nomenclature, power output, bandwidth, frequency,
antenna pattern, pulse width, pulse repetition frequency (PRF), etc. Platform characteristics as to the position of the antenna on the platform, number of elements, the pattern of the elements, the pointing vector of the radar, etc. We need an ontology for defining these data and numerous rules so that the information published by any sensor can be understood correctly by the receiving sensor to perform functions such as sensor fusion, track correlation, and target identification.

Sharing information between sensors on the same platform is also required, especially if one or more sensors are adaptively changing its waveform parameters to meet the demands of a changing environment. Figure 1 depicts a hypothesized intelligent sensor system. Each of the sensors has its own signal and data processing functional capability. In addition to this capability we have added an intelligent processor to address fusion between sensors, communication between sensors, and control of the sensors. The goal is to be able to build this processor so that it can interface with any sensor and communicate with the other sensors using ontological descriptions via the intelligent platform network. The intelligent network will be able to coordinate the communications between the sensors onboard and to off platform sensor systems. There are approaches we can exploit to build this system by using fiber optic or wire links onboard the platform. Radio frequency (RF) links using Bluetooth or 802.11 technologies can be exploited for linking these sensors onboard the platform. Between platforms other technologies may be exploited such as mobile internet protocol over RF communications links. The communications issues need to be addressed for the sharing of information and for minimizing the potential of electromagnetic (EM) fraticide. The intelligent platform should determine if there is EM interference (EMI) potential when a sensor varies their antenna’s main beam pointing vector, or changes its PRF and may thereby cause interference to a receiving sensor. Rather than have each sensor on a platform operate as an independent system we need to design our platform as a system of sensors with multiple goals managed by an intelligent platform network that can manage the dynamics of each sensor to meet the common goal(s) of the platform. This is one of the major issues we are pursuing under our sensors as robots initiative. This initiative is addressing attended and un-attended sensor platforms.

4. Ontologies

One key in building an intelligent sensor system is leveraging the efforts of the artificial intelligence (AI), the Internet, and the software communities. The Internet community is building the technology that will allow software agents to read and understand publications on the World Wide Web. Its goal is to enhance the exchange of information and to provide the tools for the Web to become more business friendly and more profitable. However, their resultant efforts can also be used to build intelligent sensor systems where multiple sensors can communicate and understand each other automatically with only minimum human intervention.

If one visits the www.w3c.org Internet site they will obtain a definition of who they are:

“The World Wide Web Consortium (W3C) develops interoperable technologies (specifications, guidelines, software, and tools) to lead the Web to its full potential. W3C is a forum for information, commerce, communication, and collective understanding.” They, along with the Defense Advanced Research Project Agency’s (DARPA) Agent Markup Language (DAML) program, are building the next generation Internet or the Semantic Web. The Semantic Web will allow one to develop Web pages that are written such that software can read and understand the contents of Web pages. Our current Web pages are developed for human consumption. They are not built for software to read and understand their contents. This is why when using search engines the responses are numerous. For example if one puts in the words “radar signal processing” then the response pages are those pages that contain one or more of these words in any order and in any place within the page. The next generation Web is being designed in a manner similar to a large knowledge base such that one can define ontologies for different interested domains, like radar or sensors in general. An ontology is best defined for our use by what motivated the development of ontologies for the Web. The following definition was taken from http://www-ksl.stanford.edu/ksl/what-is-an-ontology.html and authored by Dr. Tom Gruber.
“An ontology is a specification of a conceptualization....What is important is what an ontology is for. ... For pragmatic reasons, we choose to write an ontology as a set of definitions of formal vocabulary. Although this isn't the only way to specify a conceptualization, it has some nice properties for knowledge sharing among AI software (e.g., semantics independent of reader and context). Practically, an ontological commitment is an agreement to use a vocabulary (i.e., ask queries and make assertions) in a way that is consistent (but not complete) with respect to the theory specified by an ontology. We build agents that commit to ontologies. We design ontologies so we can share knowledge with and among these agents.”

The concept of an ontology is exactly what we need in our overall pursuit of having sensors operate in cooperation and eventually having sensor platforms operating autonomously as a robot. For them to operate cooperatively they must be able to communicate, share data and information, and understand each other and their environment. If we tried to do this with each sensor system building their own knowledge base with different knowledge base representations it would be difficult for them to communicate and understand each other. Each system would have to build software translators to understand each other. Each sensor system would have N-1 translators for a system with N sensors. This would be expensive to build, it would be processor intensive, and would generate a high maintenance cost over the life of the sensor systems.

Leveraging the approach and technology of the W3C will allow us to develop an ontology for sensors thereby having one knowledge base that can be understood by all new knowledge base sensor systems added to the overall domain including communications, radar, electro-optical, infrared, acoustic, etcetera. This approach will allow multiple sensors on one platform to inference and fuse data and information from all its sensors onboard. It will also allow for this platform to share and fuse data and information between sensors on multiple platforms located nearby or miles away within a command center. The building of ontologies is going on today. They can easily be found on the Web and can be used to build and share information within the community and domain of interest. The approach we recommend and used [10] is to not build one’s own ontology from scratch but to leverage the object oriented feature of inheritance and reference the resource descriptive framework (RDF) (i.e. an instantiation of an ontology) of those ontologies that already exist and then add those additional facts and rules required for one’s own needs. For example if a respective organization has built an RDF describing facts and rules for a transmitter, a receiver, and an antenna then if their facts and rules meet your needs then they should be referenced in a sensor ontology that one is building, rather than one building their own. In this manner one needs only to refer to the ontology containing rules and facts they wish to use and add additional rules and facts as required.

To illustrate the building of a sensor ontology consider figure 2. This is a partial model and is just the beginning of defining the classes and properties that will be needed. Not included in figure 2 are numerous other ontologies containing definitions, rules and properties we wish to use. Some of these are:

```xml
<!DOCTYPE rdf:Resource SYSTEM "http://www.w3.org/1999/02/22-rdf-syntax-ns#">  
<!ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema#">  
<!ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns#">  
<!ENTITY daml "http://www.daml.org/2001/03/daml+owl#">  
<!ENTITY xsd "http://www.w3.org/2000/01/XMLSchema#">  
<!ENTITY dct "http://purl.org/dc/terms/">  
<!ENTITY dcterms "http://purl.org/dc/terms/">  
<!ENTITY prf "http://www.ontologyweb.org/profiles/UAPROF/ccpsschema-20020710#">  
```

**Figure 2 - A Partial Model Sensor Ontology**

In figure 2 we have defined only two major classes i.e. the sensor system class and platform class. A platform has the property that it has one or more sensors onboard. A platform may be fixed such as a ground radar site or command and control center. If the platform is moving then it may be on the surface of the Earth, in the air, in
space or beneath the Earth’s surface, e.g. a submarine. A typical air platform might be a helicopter, a fighter aircraft, or surveillance aircraft. On any of these platforms the geometry for describing where a sensor is located is required. Because these types of platforms are so different, we separated them into different classes.

We have defined a sensor system as being composed of an emitter, receiver and sensor class. Here for a sensor class we are referring to the device that is emitting or receiving the wavelength of choice. For instance, if the sensor system is a radar system then the sensor class would be the radar’s antenna. If the sensor system is an optical system then the sensor class would be its lens.

5. Summary and Future Work

A motivation for a new approach for building our next generation sensor systems was presented. A background section provided an overview of some of the military funded work that is integrating artificial intelligence technology into our sensor systems was presented. An intelligent sensor system was described along with a description of ontologies. We also provided a partial model of a sensor ontology which provides the basis for multiple sensors to share information for sensor fusion and waveform diversity. Future work needs to be performed in the design of the intelligent sensor system and in the definition and development of a sensor ontology as a basis for building a system of sensors both onboard a platform and between multiple platforms.

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