An Ontology-Based Sensor Network Prototype Environment

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***Abstract*—This paper describes work-in-progress development of an ontology-based, sensor network prototype environment to facilitate research in distributed, heterogeneous sensor inference, fusion, tasking and control. Currently, the prototype environment consists of wireless sensing capabilities that include temperature, acceleration, GPS, light, barometric pressure, magnetic field and acoustic measurements, with wired visible, infrared, and other high-bitrate sensors pending integration. Communication links formed by the sensors permit the aggregation of data at the base stations. Each base station includes a process that generates a sensor data repository from the raw percepts, which is marked up using the Web Ontology Language (OWL) to reference the OntoSensor ontology. Each sensor type in OntoSensor is defined using concepts, associations, and services providing meta data about each sensor, as well as requisite knowledge for interoperability and data fusion. A software agent developed in SWI PROLOG loads the OWL sensor repositories into its knowledge base for subsequent application. Currently, the agent only supports ad-hoc queries of the sensor repositories to discover trends in the measurements. Plans for future work include demonstration of proof-of-concept utility of sensor ontologies in distributed sensor processing and control.**

Keywords: Semantic Web, Sensor Ontology, Ontology Web Language (OWL), Data Fusion

I. INTRODUCTION

Distributed surveillance is critical for military applications as well as homeland security. The ability to task, control, and fuse data obtained from heterogeneous sensors can facilitate the discovery of knowledge that is unobtainable from unitary sensor percepts [1-3]. The military has a vested interest in the establishment of heterogeneous sensing environments due to its potential for monitoring and detecting targets. Fusion of data obtained from low-level sensors, such as acoustic sensors, can result in not only the detection of a possible target, but also an approximate geo-location and heading through post processing of the measurements. Integration of higher and lower-level sensors, such as infrared cameras complemented by acoustic and temperature sensors, could reveal further knowledge about a target resulting in an increased confidence in a hypothesis. Also, sensors that consume significant power resources or that increase the probability of detection by an adversary when in use, should only activate when lower-cost sensors detect a possibly significant event of interest. For example, an array of acoustic or vibration sensors may detect an abnormality in the frequency spectrum which results in the activation of imaging or radiation detection sensors [3].

This paper describes the proof-of-concept implementation of a Semantic Web enabled, heterogeneous sensor network. The paper is organized as follows. Section 2 provides a brief overview of the methods and infrastructure used in the prototype and the creation of distributed, sensor repositories. Section 3 discusses the capabilities of the current implementation and possible future directions for this project.

II. METHODS

A. Wireless Sensors

Currently, the wireless environment consists of two networks, each having multiple sensor nodes built from parts available from commercial vendors. For example, sensor types include MEP410, MEP510, MTS420, and MTS310 available from Crossbow Technology Inc. The MEP410 and MEP510 are environmentally hardened mote platforms. The MEP410 platform sensing capabilities include ambient light, barometric pressure, photo-sensitive light, relative humidity, and temperature. The MEP510 platform is capable of relative humidity and temperature measurements. A MIB510 gateway is used for the aggregation of data obtained from the MEP410 and MEP510 platforms. Also, MTS420 and MTS310 data acquisition sensing elements are coupled with MICAz processor/radio boards. The MTS420 sensor boards have capabilities that include bi-axial accelerometer, ambient light, barometric pressure, temperature, GPS, photo-sensitive light, and relative humidity measurements. The MTS310 sensor boards have bi-axial accelerometer, acoustic, and photo-sensitive light sensing elements. The MTS420 and MTS310 deployment uses a MIB520 network gateway which provides the flexibility to collect data from remote deployments. The MicaZ boards operate in the 916 MHz or 2.4 GHz frequency range and handle the data processing and communication needs for the platform. The processor/radio boards run Crossbow's XMesh software that allows dynamic formation of communication links between the nodes.

B. OntoSensor

OntoSensor [2] is a Semantic Web compatible ontology developed using Protégé 2000 [4]. OntoSensor references and extends the IEEE Suggested Upper Merged Ontology (SUMO) [5], which defines general concepts and associations. OntoSensor is based in-part upon SensorML [6], which defines associations and properties common to sensors. OntoSensor deviates from SensorML since it lacks the semantic richness, such as axiomatic-grounded terms, which may be required for automated data fusion and inference in a distributed sensing environment.

Currently, OntoSensor includes knowledge models for the data acquisition boards, sensing elements, and processor/radio units contained in the Crossbow 2006 catalog [7], as well as preliminary definitions of a variety of imaging sensors. OntoSensor contains a hierarchy of sensor classes and describes sensor attributes, capabilities, and services. OntoSensor concepts and associations are instantiated in distributed repositories updated by the base stations of the network. The data model for a given sensor contains meta data such as sensitivity, performance range, and accuracy for the sensing elements, as well as physical characteristics such as mass, radio frequencies, dimensions, and power supply information for the platform.

C. *Distributed Repository*

Currently, the prototype network is comprised of two deployments with independent base stations that store the collected data. Two computers interface with the associated base stations using Crossbow's MoteView application to retrieve data which is stored in a PostGRE database. Each base station executes custom software that generates OntoSensor referenced OWL repositories from the collected sensor data. The software is a preliminary implementation of a web service that will be evoked at the base stations for posting OWL pages within the network environment.

Successful reference of OntoSensor requires *a prori* knowledge of the sensor platform class associated with a given node identification number. Later development will circumvent this dependency through custom software development on the processor boards such that they are self describing. The platform class is used as a primary key to retrieve inherited and unique properties defined through constraints in Protégé 2000 and exported to OWL.

The software periodically checks for a database update using PostGRE ODBC drivers and retrieves updated tuples corresponding to raw sensor percepts. The retrieved tuples are then post-processed and marked up using OWL.

A naive yellow pages facility has been created that contains the URLs for the distributed repositories. An agent implemented using SWI PROLOG accesses the yellow pages and loads the listed repositories of interest into its knowledge base.

III. DISCUSSION

The current agent is capable of only ad-hoc queries. The agent can query the sensor knowledge repositories to find motes deployed in a given geo-location, or find the average temperature or barometric pressure in a region of interest, etc. Future work will involve investigation of higher-level data fusion methods using additional knowledge repositories and distributed reasoning strategies.

The agent is currently capable of querying the designated yellow pages and retrieving URLs of sensor repositories on various base stations. The ability for the agent to select and combine web services based upon either a user request or other goals is desired. OntoSensor may be further extended using OWL-S [8] to capture higher-level knowledge about sensor services.

From the view of the sensor service requestor, the deployed networks will appear as a seamless environment that provides a set of services. Implementation of this environment will require creation of a sensor service broker. The service broker orchestrates services based upon the needs of the user and the available services offered by the sensor service providers [9]. The sensor service providers are the actual sensor networks or base stations that register their respective services with the broker and publish the OWL associated with its network. The sensor service requestor locates the desired services provided by the broker and can task and query the sensor service provider.

Future development will involve the integration of more complex sensors into the network including imaging sensors such as video, infrared, terahertz and other sensors that provide rich, high-bitrate data [10]. For example, a ThermaCam Merlin mid-wave infrared camera from FLIR Systems Inc., or a camera of similar capability, is currently pending integration into the prototype environment. Merlin connects directly to the LAN and will be configured to operate as its own base station. Merlin's software development toolkit (SDK) will be used for obtaining periodic frames and marking up knowledge about the captured images in OWL. The images will be stored at the associated base station in a database that can be queried by agents and end users. Also, the images will be associated with meta data that includes image format, date, time, resolution, location and other properties about the sensor that captured the images and the surrounding environment. The meta data contained in OntoSensor describing the Merlin or similar cameras may be used to deduce further information about the image. Furthermore, a time series of images can be retrieved from a distributed repository and post-processed to extract intrinsic knowledge that can be combined with lower-level readings such as pressure, acoustic, or magnetic field measurements to potentially increase the confidence in a target or activity of interest.

IV. CONCLUSION

A proof-of-concept, ontology-based sensor network prototype has been discussed. The prototype is capable of referencing the OntoSensor ontology, generating OWL markup of sensor percepts, and processing ad-hoc queries. Future work will seek to incorporate more complex sensors into the network, experiment with data fusion and inference capabilities of the agent, and improve the process of locating and executing sensor services.

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