

Target Resolution in Distributed Sensor Systems

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ABSTRACT

Remote Situation Awareness capabilities using a field of microsensors are now feasible using recent electronics and communications improvements. For instance, the DARPA SensIT program is based on the concept of cheap, small, and smart devices that host multiple types of onboard sensors, which also possess considerable embedded processing and storage capability, and short-range wireless communications. The devices will be quickly and flexibly deployed for varying missions, potentially in very large numbers, on buildings and bodies, on vehicles, and on ground and under water.

Power consumption is critical to surveillance lifetime as well as packaging and deployment techniques. Collaborative processing approaches that build on local collaboration between sensors are attractive because they restrict most communications to near-by sensors, minimizing communication energy requirements and decreasing the possibility of detection and jamming.

We discuss techniques to implement Collaborative Signal Processing on distributed networks, including:

- Associating data sets for the same target from multiple nodes to develop a system-level count of how many targets are present
- Selectively fusing position data from multiple nodes, using those nodes in the best position to give useful data
- Iterating feature estimation updates based on asynchronous inputs from multiple nodes
- Distributing processing components across the sensor network to minimize power usage

OVERVIEW

Key to the ability to field small, dispersed, autonomous forces is faster and more local access to information to support diverse and rapidly changing situations encountered during these missions. Increasingly, US forces are called on to participate in activities in areas where little previous information has been gathered on the terrain, where the potential exists for conflict with non-traditional combatants using non-traditional tactics, and in areas not well supported by existing INTEL systems. Recent military deployments such as Bosnia and Somalia are examples.

Technology is now available to aid in surveillance of the battlespace at a cost that makes it affordable for individual soldiers and small units to use. Low cost, easily deployed, micro airborne, ground, and littoral sensor networks are the key to providing the type of information needed by these small soldier teams.

Low cost organic (i.e. dedicated and controlled by the soldier) sensing devices can extend a small unit's area of influence by providing on-demand local gap-filling situation awareness sensors for missions

Report Documentation Page

Report Date 00 Oct 2001	Report Type N/A	Dates Covered (from... to) -
Title and Subtitle Target Resolution in Distributed Sensor Systems	Contract Number	
	Grant Number	
	Program Element Number	
Author(s)	Project Number	
	Task Number	
	Work Unit Number	
Performing Organization Name(s) and Address(es) BAE Systems Advanced Systems and Technology Information and Electronic Warfare Systems PO Box 868 Nashua, NH 03061	Performing Organization Report Number	
	Sponsor/Monitor's Acronym(s)	
Sponsoring/Monitoring Agency Name(s) and Address(es) Department of the Army, CECOM RDEC Night Vision & Electronic Sensors Directorate AMSEL-RD-NV-D 10221 Burbeck Road Ft. Belvoir, VA 22060-5806	Sponsor/Monitor's Report Number(s)	
	Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes See also ADM201471, Papers from the Meeting of the MSS Specialty Group on Battlefield Acoustic and Seismic Sensing, Magnetic and Electric Field Sensors (2001) Held in Applied Physics Lab, Johns Hopkins Univ, Laurel, MD on 24-26 Oct 2001. Volume 2 (Also includes 1999 and 2000 Meetings), The original document contains color images.		
Abstract		
Subject Terms		
Report Classification unclassified	Classification of this page unclassified	
Classification of Abstract unclassified	Limitation of Abstract UU	
Number of Pages 9		

ranging from reconnaissance to targeting of precision guided munitions. These sensors give the soldier the immediate ability to see “what’s over the next hill” and “what’s around the next corner” – the information that can make the difference between failure and success.

These sensor networks encompass a variety of sensor types, deployment modes, endurance, and capability. Sensor detection ranges vary from kilometers for air and ground vehicles to meters for personnel and parked ground vehicles. Distributed sensor networks with large numbers of nodes provide more opportunities to follow targets, with greater likelihood that some set of sensors will be optimally placed for classification and verification.

Distributed sensor networks pose new challenges in the design of algorithms for processing the sensor signals into useful information. Raw data that is initially distributed among many sensor nodes must be combined to generate the desired information; however the use of interconnecting radio frequency (RF) links must be minimized to avoid detection and jamming as well as to conserve power. Power consumption is critical to surveillance lifetime as well as packaging and deployment techniques.

Collaborative processing approaches that build on local collaboration between sensors are attractive because they restrict most communications to near-by sensors, minimizing communication energy requirements. Collaborative Signal Processing involves:

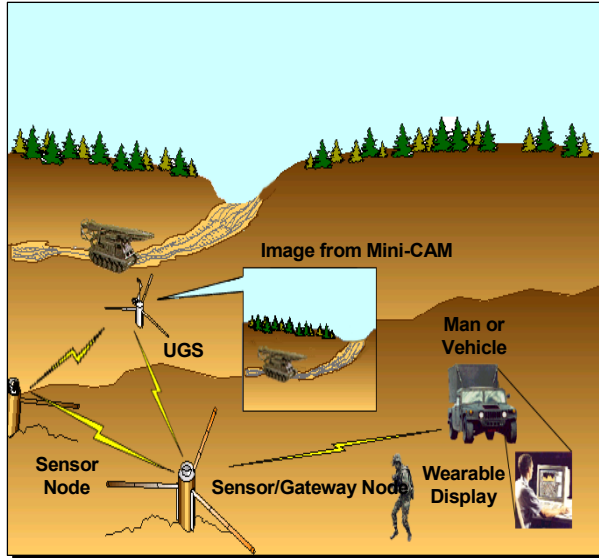
- Low level sensor processing which occurs local to a sensor node
- The exchange of data among sensor nodes to enable decisions and other high level data to be derived from raw sensor signals
- A process in which a consensus is reached among sensor nodes about what is occurring in the physical world and reports or digests are created for transmission to users
- The minimization of power consumption on sensor nodes, including communications, signal processing, and sensors.

The DARPA Sensor Information Technology (SensIT) program goal is to create a new class of innovative and effective software for distributed micro sensor networks, *which will enable ad hoc fields of simple, cooperating sensors to produce high-quality information for diverse functions and scales while minimizing resource consumption.*

The SensIT program is based on the concept of inexpensive, small, and smart devices that host multiple types of onboard sensors, which also possess considerable embedded processing and storage capability, and short-range wireless communications. These devices will be quickly and flexibly deployed for varying missions, potentially in very large numbers, on buildings and bodies, on vehicles, and on ground and under water.

PROVIDING REAL-TIME SITUATIONAL UNDERSTANDING

Networks of distributed sensor systems can be used to collect torrents of raw data, such as temperature readings or traffic reports. Each sensor node has unique data which is often worth collecting and storing. However, in the military applications under consideration here, that raw data must be refined into a short, high level summary for use by the soldier in the field. The various levels of the data reduction hierarchy are shown in Figure 1:



- **Observations**
 - Data from acoustic, seismic, ...
- **Battlefield Intelligence**
 - # detections/SNR
 - event time
 - target class/features
 - bearing, velocity
 - transient info
- **Situational Awareness**
 - #, type of targets
 - position and track
 - activity status (moving, stopped, loading,...)
- **Situational Understanding**
 - e.g. missile launcher coming from X, probably going to Y

Figure 1. Data Analysis Hierarchy

At the sensor node level, targets can be detected, identified and tracked within the range of the node. Across the sensor field, the target identification and tracking information needs to be accurately combined in order to prevent duplicate target reports. This level of fusion provides situational awareness of what each target in the sensor field is doing. For a vehicle detection system on an open road, this could result in hundreds of target reports per day. But what the soldier-user needs is a more narrative description regarding the targets he or she is most interested in and what they are doing. The ultimate goal of Collaborative Signal Processing is to provide that level of situational understanding to the end-user.

Resolution of multiple targets is key to the successful development of distributed systems. If data from the same target is incorrectly assigned to two different targets because the detection reports come from two different nodes, then the information reported by the sensor system is compromised; in addition, transmitting the extra, erroneous reports will consume scarce power resources. By knowing the number of targets being detected, the field can successfully combine similar target reports and more efficiently supply outputs.

Our approach to this problem is to use data from multiple nodes to localize and count the number of targets prior to tracking and classification. Correctly associating data from multiple nodes with the same target can be accomplished by looking at node detection behavior as targets move through the sensor field.

EXPERIMENTAL DATA - SITEX 00

The SensIT Program Team designed and executed the SITEX 00 field test in order to collect data on target vehicles moving through a dense sensor field. The SITEX 00 field test occurred at the Marine Corps Air Ground Combat Center (MCAGCC) facility at Twenty Nine Palms, California, during August, 2000. Sensors deployed included seismic sensors, omnidirectional acoustic sensors, directional passive IR sensors, and wideband acoustic sensors. Figure 2 shows the sensor lay-down.

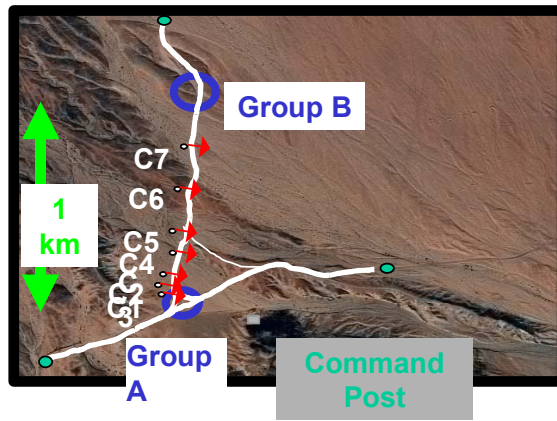


Figure 2. Sensor positions at SITEX 00 test.

Data was collected for multiple runs featuring a wide range of quantity and type of targets. For our analysis, we selected a single vehicle run and a multi-vehicle run. We used data collected from the seismic sensors in the A cluster, located at the intersection of the North-south and the East-West roads. These comprised a set of about one dozen sensors, with average nearest-neighbor distance around 20m.

DATA ASSOCIATION ALGORITHMS

Deployed groups of sensors can pick up targets of interest on multiple sensors. This provides an opportunity and a challenge. The opportunity arises from obtaining multiple glimpses of the target, and from being able to track the target through the sensor field. The challenge is to correctly associate multiple target reports with the same target, especially when multiple targets are in the sensor field detection region. Figure 3 shows a bearing vs time plot of three vehicles transiting by a sensor. Note that the bearing sweep past the closest point of approach (CPA) of all three vehicles is clearly visible, while at farther distances all the targets combine to form one target track.

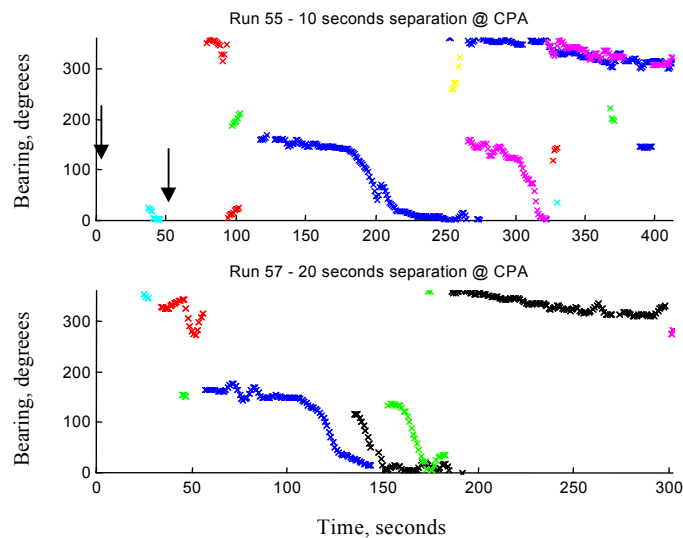


Figure 3. Bearing vs Time plot of three-vehicle convoy

Our approach is to exploit the fundamental signal properties of power, frequency, and bearing to localize a target near one sensor or between two sensors. This should provide the ability to resolve multiple targets in a sensor field if there are multiple sensors between them.

As a point of reference, Figure 4 shows the number of nodes detecting a target vs. time for a two-vehicle convoy passing through the cluster. Also shown is the estimated number of true targets that could have been detected by the sensor field. Local determination of how many targets are present can provide a significant reduction in the number of outgoing messages.

By combining detection information from neighboring nodes, we can determine the number of targets present and their approximate location. This approach is useful in resolving targets with separation greater than the size of the neighborhood of nodes. Figure 5 shows the target count for the single-vehicle scenario. In this scenario, the target moved back and forth along the road near the sensors, each time passing far beyond the sensor detection range before turning around. The algorithm successfully combines the detection information from multiple nodes to get the correct number of targets in the sensor field.

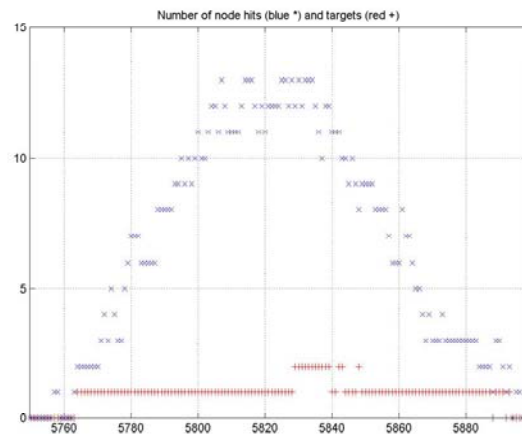


Figure 4. Number of target detections in A cluster (blue) and number of targets declared (red).

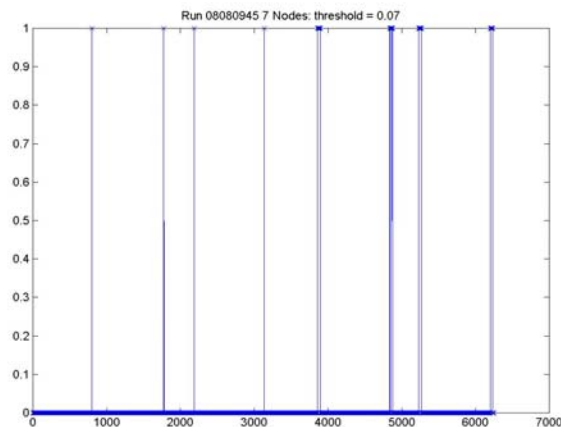


Figure 5. Number of targets detected vs time, single target, 8 transits

Figure 6 shows the estimated Y position vs. time for four target passes. The target position is determined using the node with the strongest signal and its three neighbors. Since the target was passing through the cluster along mostly the north-south axis, the x-position of the target does not change substantially. Note that each plot clearly shows the target motion through the field, from south to north and back and then repeating. The plots also show position irregularities apparently due to differing response between sensors.

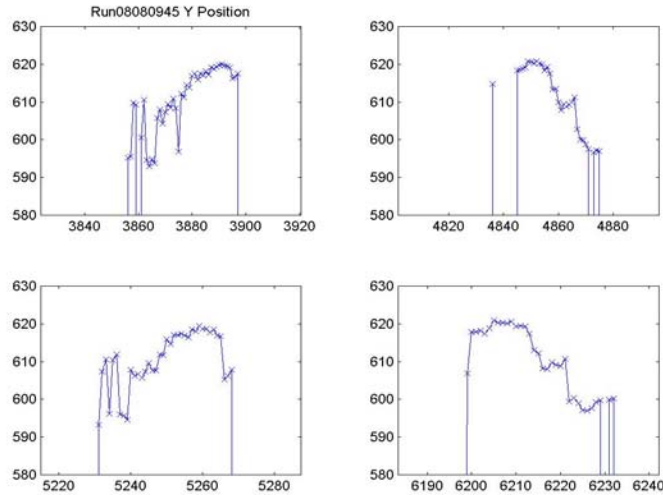


Figure 6. Estimated Y position vs time for 4 target passes.

For the multiple vehicle scenario, Figure 7 shows the algorithm results indicating the number of targets detected at each time interval. This shows good agreement with the actual number of targets present in or near the cluster at each time interval in this scenario. Figure 8 shows the number of estimated targets as two targets passed through the cluster. The first target is detected, then the second one, and then as the first one recedes from the cluster, the number of targets present drops to one again and then zero.

Target position estimation is not as reliable for multiple targets as when only one target is present. Multiple targets mean that fewer nodes are associated with each target. The irregular spacing of nodes, as required for operational use of distributed sensor systems, means that certain nodes tend to have higher signal response to virtually any target and tend to dominate the position calculation. Therefore, estimated target positions tend to stick to the nodes with the stronger response rather than follow the target through the cluster. As shown in Figure 9, this results in target positions for the two targets that don't fairly represent their motion through the sensor field.

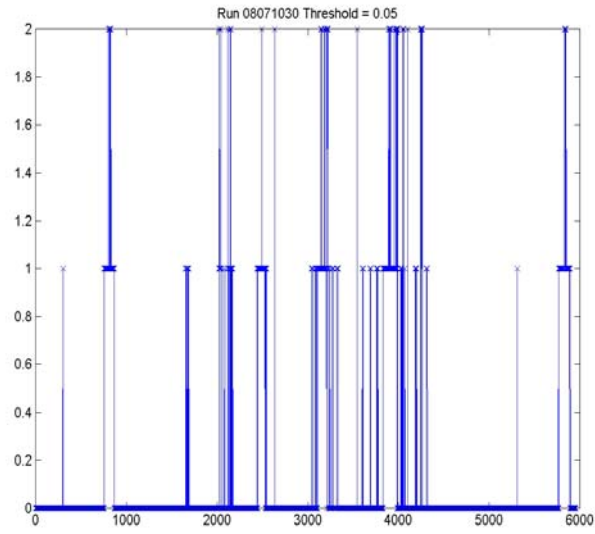


Figure 7. Number of targets estimated vs time for multiple vehicle run

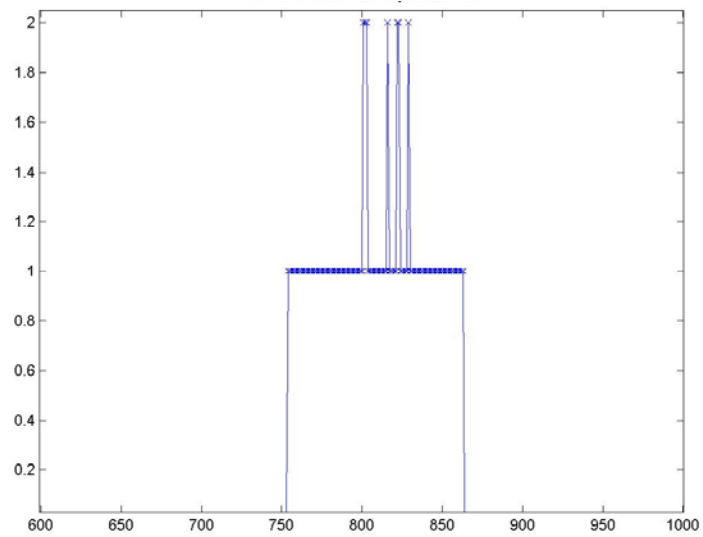


Figure 8. Number of targets estimated vs time for two targets

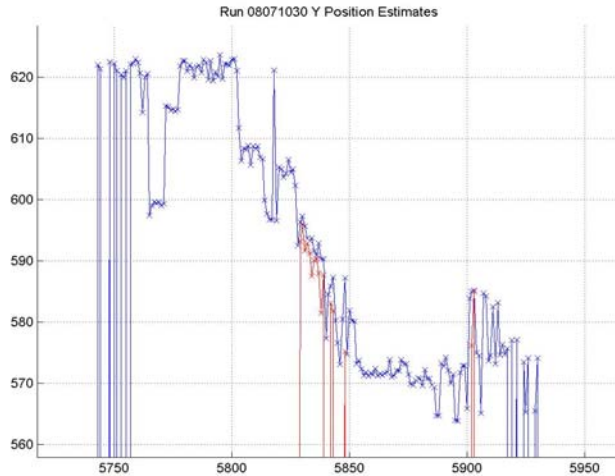


Figure 9. Y position estimates for two targets

A second algorithm, which relies on the difference in bearing observed at two nearby nodes as a target moves through the nodes, provides better target resolution as well as precise location between the adjacent nodes. Figure 10 shows the Y-position vs. time of a target moving north between two nodes. With this approach, accurate counts could be made for convoys of vehicles so long as vehicle separation is greater than node spacing.

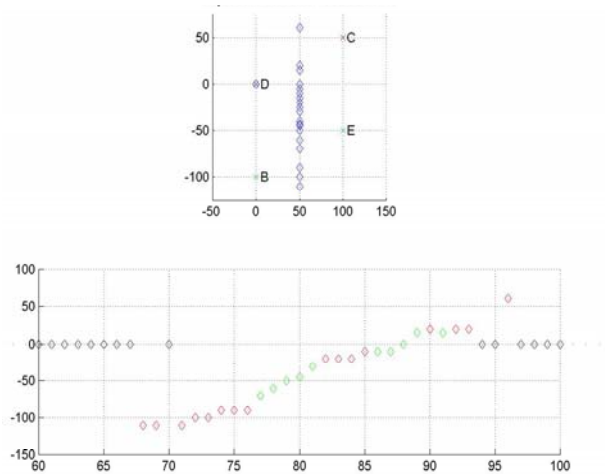


Figure 10. Target position determined using bearing difference between two nodes.

CONCLUSION

Analysis of field data indicate that combining post-detection data from neighboring sensors can aid in data association and target track processing. Algorithms to count and locate targets inside sensor clusters have been developed. These target resolution/data association algorithms will be implemented in real-time and their performance measured on multiple types of scenarios during additional SensIT field tests which will occur during FY2002.

ACKNOWLEDGMENTS

This material is based upon work supported by the Space and Naval Warfare Systems Center - San Diego and DARPA ITO under Contract No. N66001-00-C-8054. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the Space and Naval Warfare Systems Center - San Diego or DARPA ITO.