Classification and Location of Ground Vehicles using Networked Microsensors

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Abstract

This paper investigates the localization and classification of ground vehicles using a field of microsensor systems employing acoustic, seismic, and magnetic sensors at each node location. Specific results will focus on the ability of individual nodes to detect ground vehicle targets of varying types and provide information on those vehicles. We also discuss the fusion of information from multiple nodes to further enhance target information over time

Key Words: Low cost miniaturized sensors, multi-sensor fusion, multi-node fusion, vehicle localization/classification

Introduction

Sanders is developing remotely deployable unattended ground surveillance systems[1]. These systems consist of a set of small, individual nodes. The remote deployment capability allows unobtrusive monitoring in hostile or neutral areas where in-situ placement is not practical. Each individual node will be able to detect, classify, and track targets of interest at short range, using a variety of miniaturized sensors. Enhanced classification and localization capabilities will be provided at the field level by combining information from neighboring nodes.

This paper discusses some of our development work in the following areas:

1. System development
2. Target Classification
3. Multi-sensor and Multi-Node Fusion

Concept of operations:

Applicable missions for remotely deployed unattended sensor fields include the following:

- Detection/classification/tracking of time-critical mobile targets (TCTs). For instance, identifying a weapons launching vehicle within a convoy.
- Area denial. Such a field can be used in place of a mine field. The node lifetime is a critical limiting factor for area denial use.
- Characterization of man-made structures. For instance, determining whether intruders are present in secured buildings or determining whether buildings are in use.

[1] This material is based upon work supported by the Army Research Laboratory under contract DAAL-01-96-2-0001

Form SF298 Citation Data

Report Date ("DD MON YYYY") 00001999	Report Type N/A	Dates Covered (from... to) ("DD MON YYYY")

Title and Subtitle Classification and Location of Ground Vehicles using Networked Microsensors	**Contract or Grant Number**
	Program Element Number
Authors	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Sanders a Lockheed Martin Company P.O. Box 868 Nashua, New Hampshire 03061-0868	**Performing Organization Number(s)**
Sponsoring/Monitoring Agency Name(s) and Address(es)	**Monitoring Agency Acronym**
	Monitoring Agency Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes	
Abstract	
Subject Terms	
Document Classification unclassified	**Classification of SF298** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** unlimited
Number of Pages 8	

- Bomb damage assessment. Deployed in conjunction with weapons, sensor fields can be used to monitor follow-up enemy activities. With an imaging component, in-situ bomb damage assessment can be provided.
- Forward surveillance. A remotely deployed or hand-emplaced system with an imaging component can be used to identify and record unusual activities such as troop or vehicle movements or the committing of atrocities

The area that can be covered by a set of nodes is driven by the following factors:

- Sensor (Detection/classification) range
- Comms link range
- Mission (e.g. area denial missions require detection of perimeter penetration so that any detection within the field is sufficient; TCT tracking requires multiple detections within the field in order to establish a track)

Specific design features of a short baseline system are much different than those used for long baseline acoustics systems used in other applications. Trackers, classifiers, and the sensors themselves are designed and tuned for much different operating points in the two extremes. As an example, a tracker operating at close range as a vehicle passes must handle a much higher bearing rate than one operating at long range. Close cooperation between sensors at short range is more feasible due to reduced transmit power consumption. A short baseline system also provides more up-close looks at the target than a long baseline system does over the same time period, since the target will pass by more sensors in the short baseline concept.

System Development

We have developed a prototype system, used in data collection exercises, consisting of four nodes, each of which contains three types of sensors. A typical node is shown in figure 1. Each sensor node consists of a three-element electret microphone acoustic array, a single axis (vertical) moving coil geophone, and a three axis GMR magnetic sensor. The sensor nodes are deployed by hand. Our current system includes four such nodes.

In field tests, the nodes are separated by approximately 100 meters. This architecture resembles a small scale network "cluster." The signal data acquired at each node is transmitted over cables to a remote location (100 meters from the master node) where the signals are processed and fused in real time and target reports are produced. This processing is performed on a Pentium-class PC. Individual target report files are produced for each of the individual sensor nodes. In addition, a fifth file is produced containing target reports from the network as a whole. This file will have refined target classification and position estimates resulting from the fusion of the individual sensor data. All five target report files are saved to a ZIP disk. A user interface is provided so that run number, beginning, and end of run can be entered by an operator.

Figure 1. Prototype sensor node

Figure 2 shows the positioning of sensor nodes and the data acquisition system for a typical exercise. Sensor nodes are deployed on both sides of a road over which target vehicles will travel. The hardware and processing configurations are shown in Figures 3 and 4.

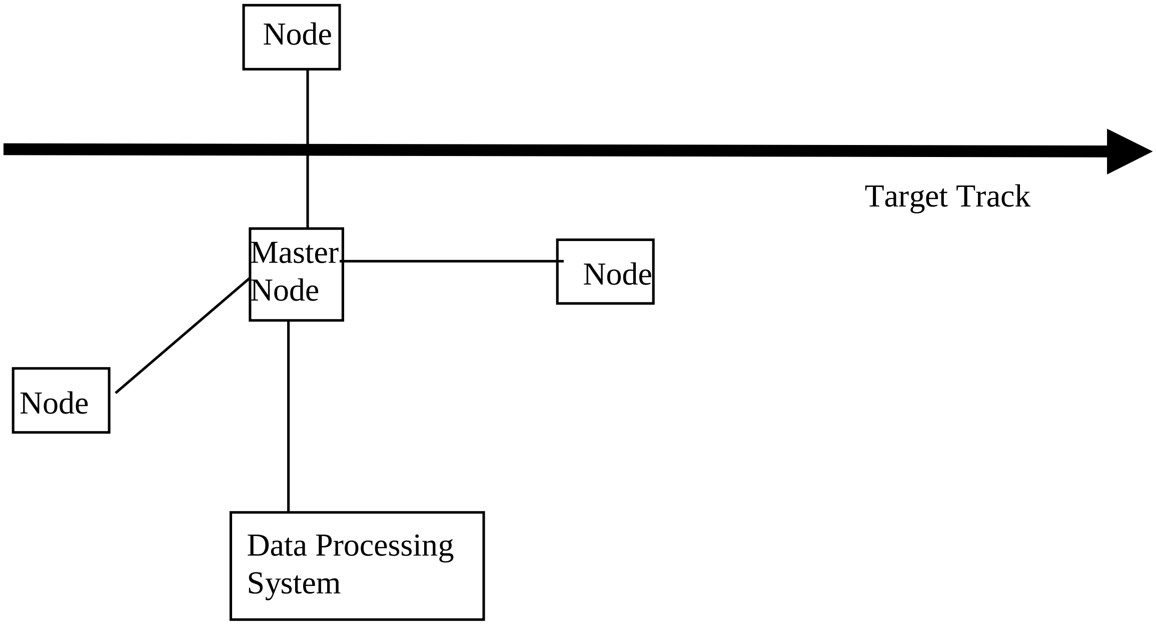

Figure 2. Notional Physical Layout

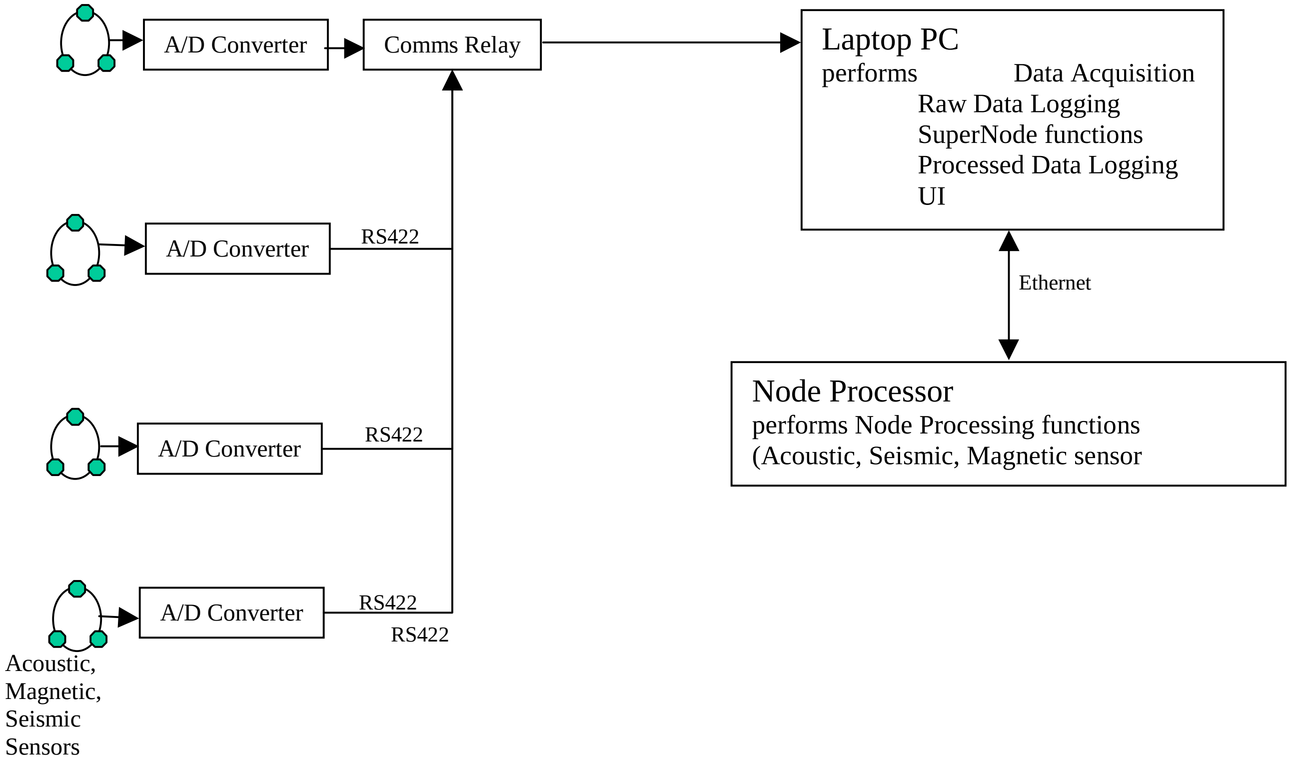

Figure 3. Hardware configuration

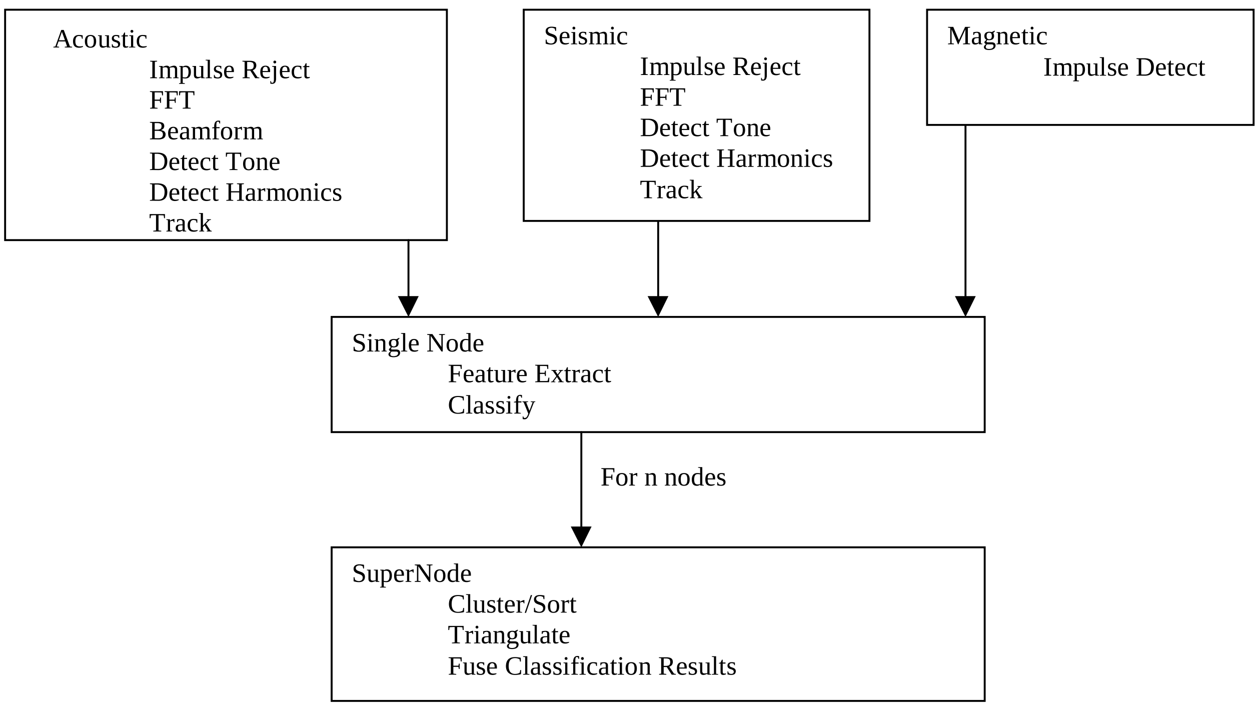

Figure 4. Processing Configuration.

Signal Processing

Post-data collection acoustic processing on the collected data included:

- Beamforming data from the three microphones to obtain bearing data
- Identification and tracking of tones
- Creation and tracking of target tracks, consisting of related acoustic and seismic tones
- Measurement of target features and classification of target type

Acoustic tones at similar bearings and frequencies are combined to form target tracks. Seismic tones with frequencies close to acoustic tones are also incorporated in target tracks. Ideally, there should be only one track per target. However, rapid changes in bearing near the point of closest approach (CPA) can cause the tracker to break one track into multiple tracks. Adjusting the tracker parameters to carry the target thru CPA decreases the ability to resolve multiple targets.

Target classification activities focused on extracting target track information on number of cylinders and treaded vehicle vs wheeled vehicle discrimination. We focused on evaluating feature data in the time period immediately following CPA. CPA was determined based on the ratio of the target's current power to the power in previous frames. A 10 dB drop in power from a recent peak indicated that the peak was the CPA.

We measured the number of cylinders based on the ratio of strongest acoustic lines to harmonic frequencies. A multi-cylinder engine is expected to present a spectrum with multiple lines due to engine firing cycles, some of which are stronger than other lines. An example spectrogram showing engine firing lines is shown in Figure 5.

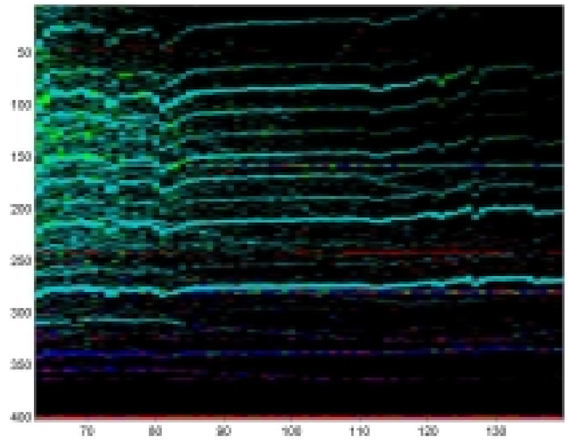

Figure 5. Acoustic spectrogram

Wheel/tread discrimination is based on the degree of overlap of the target track's seismic and acoustic tones. Analysis of data indicates that tracked vehicles include strong seismic lines at low freqs which are not caused by acoustic sources (i.e. do not appear as the strongest acoustic lines). This indicates that comparing the acoustic power to the seismic power of the strongest seismic lines is a useful discriminator between wheeled and treaded vehicles. As an example, Figure 6 shows the seismic (left) and acoustic (right) spectrograms for a battle tank. The acoustic spectrum shows the characteristic engine firing lines discussed above, as well as tread lines corresponding to seismic tones at about 40 and 20 Hz.

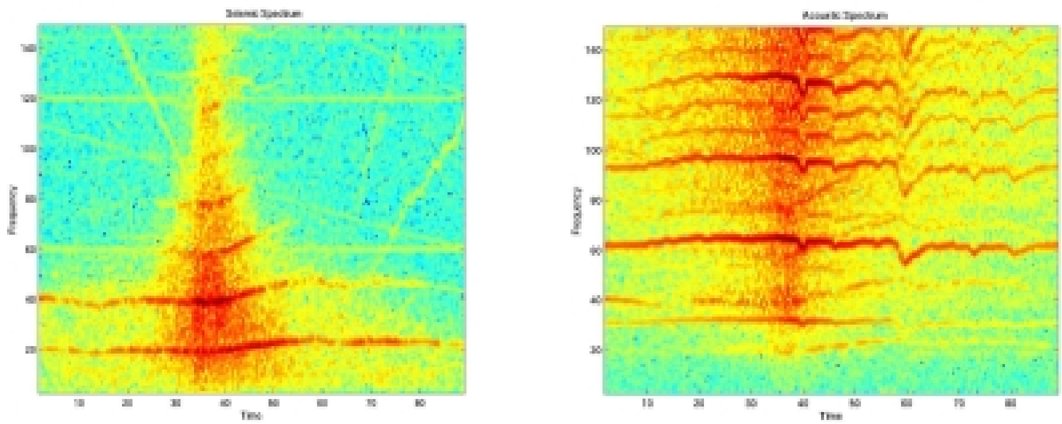

Figure 6: Example treaded vehicle seismic spectrum (left) and acoustic spectrum (right)

Data Analysis

At the Spesutie Island test in December 1998, data was collected from two prototype nodes for several vehicles. Acoustic tone tracks exceeding 200 seconds in duration were observed on multiple occasions. We resolved multiple vehicles in convoy. Analysis of the track bearing information indicates good positional accuracy with the vehicle track. Classification features were accurately measured on several runs at ranges up to 500 m.

The test set-up involved a road along which vehicles traveled from north to south and back. Our nodes were deployed to the west of the road. For two nights of tests, the nodes were deployed paralleled to the road about 10m from the road; for the other two nights the nodes were deployed perpendicular to the road at 10m and 60m from the road. When targets were between 30m and 500m of a node, the bearing was determined to within 9 degrees of the target’s true bearing. Bearings for targets closer than 30 m are less accurate due to the large rate of bearing change at close distances. A true bearing vs measured bearing plot is shown in Figure 7.

A major issue in correctly tracking targets is maintaining a single track as a vehicle goes by (including going through CPA) while distinguishing between multiple vehicles traveling together, as in a convoy. An example of multiple vehicle tracking is shown in figure 8.

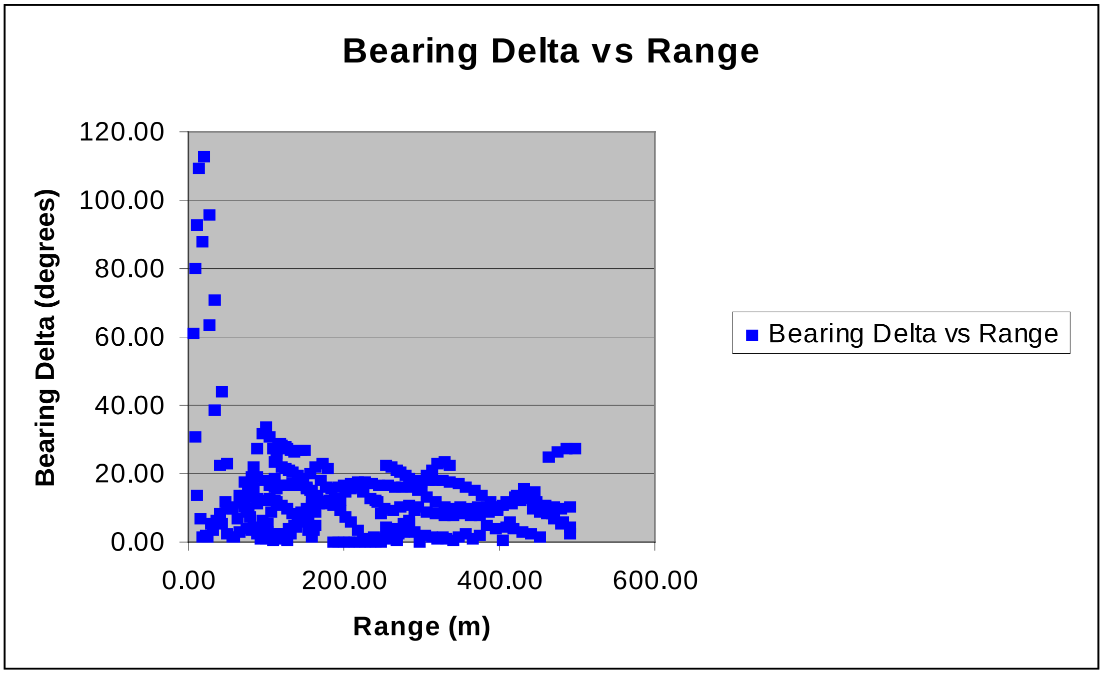

Figure 7. Bearing accuracy vs range for range less than 500 m for one target run. Lower accuracy (higher bearing delta) at short range is due to time skew and tracking lag at closest point of approach.

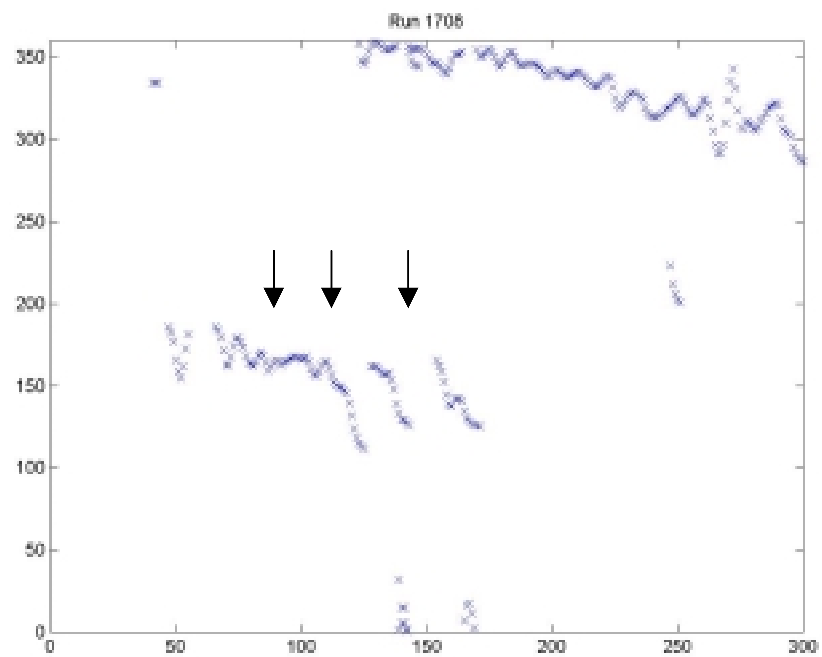

Figure 8. Bearing (left axis, in degrees) vs time (bottom axis, in seconds) for three vehicles approaching from the south and exiting to the north. Notice three distinct bearing sweeps (indicating point of closest approach) at times 120, 150, and 180 seconds.

Target reports from each node consist of bearing, list of component tones, tone powers and SNRs, and preliminary classification information. Target reports from each node are fused into a single target report when the report bearing strobes intersect at a reasonable distance, and some or all of the component frequencies match. However, in high-clutter environments, selection of which target reports from different nodes to combine into a single fused report is problematic.

Fused target reports provide range information which is extracted by one of several techniques, the most basic of which is triangulation. Alternative techniques include computing combined target location PDFs, establishing an extended Kalman tracker, and minimizing bearing error from each node to the target. When the target is too far away compared to the baseline between the sensor nodes, the localization error in the range direction becomes enormous as the bearing strobes become nearly parallel. This effect can be minimized for outbound targets by forcing a simple target motion model (e.g. straight line motion), but at the cost of losing sensitivity to target maneuvers.

Classification features are calculated in each frame. However, these features are strongest when the target is closest to the node, so we report only those values at the CPA and in the 15 frames following. These values are averaged together to report a final feature estimate. Example estimates are shown in figure 9.

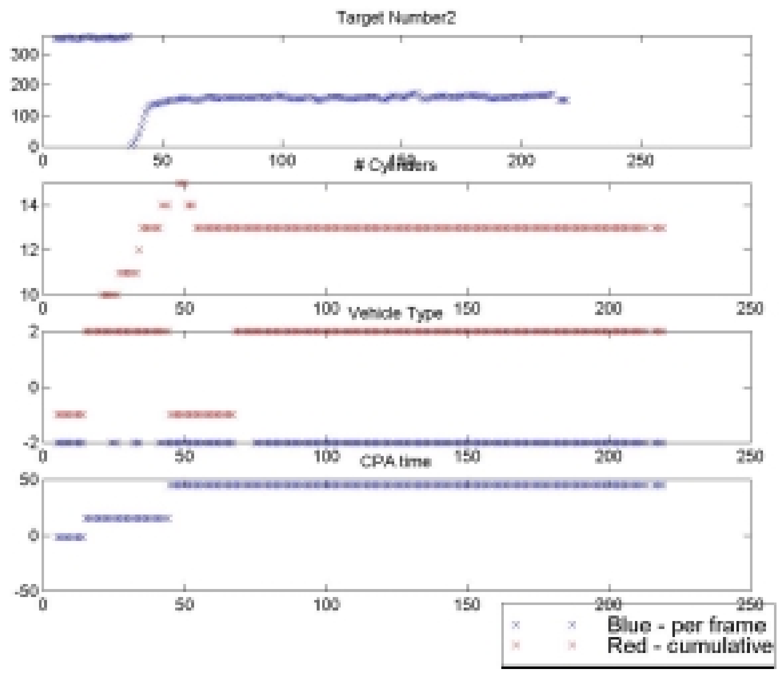

Figure 9. Track and feature statistics for a main battle tank pass-by. All plots show time in seconds along the bottom axis. The top plot shows bearing, followed by number of cylinders estimate and wheel (value=1) vs tread (value=2) estimate, and calculation of CPA time in the bottom chart.