TARGET CLASSIFICATION AND COUNTING ALGORITHMS FOR UNATTENDED ACOUSTIC SENSOR SYSTEMS

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Unattended Ground Sensor technology used for battlefield awareness and other wide area surveillance applications requires state-of-the-art algorithms to address the unprecedented challenges faced in detecting, classifying and tracking military combat vehicles. Traditional acoustic sensor systems experience unacceptable performance degradation when confronted with multiple target scenarios in dynamic, and highly mobile environments in which today's forces must operate. Recent developments in acoustic signal processing methods at the Army Acoustic Center of Excellence (ACOE) are helping to realize innovative solutions to the difficult problems inherent with multiple target tracking and ground vehicle classification.

Target classification and ID using acoustic sensors has proven to be a challenging problem due to the lack of robust target features that remain constant with a vehicle's directional motion and variable engine load. Variations over the signal range of interest resulting from changes in ambient noise levels and atmospheric propagation conditions throughout the diurnal cycle further complicate the ability to extract a consistent set of attributes for classification. Military vehicles powered by internal combustion engines normally have a single dominant tone associated with the engine firing rate (EFR) that depends on the engine type and number of cylinders in the engine. As a result, the vehicle spectra include a family of narrowband harmonically related features that are dependant on the EFR. The relative position of the EFR is dependent on the vehicle's physical structure, while the instantaneous frequency and relative positions of the corresponding narrowband components rely on its speed, gear, engine loading and RPM. The spectra of the time series derived from a vehicle's engine noise under favorable conditions contain useful features for classification in view of the fact that they reveal the dominant periodic effects of rotating machinery (e.g. internal combustion engines, turbines, gears) as well as other periodic phenomena, such as tire noise and track-road impact.

In response to the Army's need to deploy a reliable target classification algorithm for unattended acoustic sensor systems, a cylinder classification and target ID algorithm was developed in support of the RAPTOR program and the Advanced Acoustic-Seismic Systems STO (IV.SN.2000.01). The classifier was trained on a feature space derived from the harmonic structure characteristic to acoustic emissions from typical ground targets found in the battlefield environment. Our approach facilitates a novel characterization of these signals prior to classification and has proven to be effective in solving some of the fundamental problems associated with classifying and identifying diesel-powered ground vehicles in variable SNR environments. A reduced feature space representation exploits the structured ordering for the principal narrowband components found in a vehicle's engine noise and provides a means for efficiently discriminating between four cylinder groups and seven target ID classes. Engineers at ACOE have shown that the structured ordering of the three most prominent engine noise harmonics are a sufficient basis in developing a robust statistical template for classification. The algorithm was developed using a comprehensive vehicle signature database collected during the Wide Area Munition (WAM) and Integrated Acoustic Sensor (IAS) programs. The resulting optimal Bayesian classifier shows superior classification performance over existing template-based techniques for four distinct cylinder classes and eight ground vehicles classes when class estimates are integrated over time. Theoretically it has been shown that the classifier performs well even in situations where strict independence cannot be imposed on the probabilistic nature of events being classified. Current performance measures show a consistent cylinder classification and target ID > 85 % .

In addition to providing extended range surveillance and target classification and ID, acoustic overwatch sensor systems (AOS) are also used to track multiple targets on the battlefield. A network of overwatch sensors remotely deployed in conjunction with a central processing node (or gateway) can provide early warning and assessment of enemy threats, near real-time situational awareness to commanders, and may reduce potential hazards to the soldier. When a network of multiple acoustic sensors is used, measurements from distributed arrays are reported to a fusion center that sorts the sensor measurements and estimates the location and kinematics of identified sources of interest. Target tracking in noisy, cluttered environments is treated as a problem in associating detected target observations with target tracks. Vehicle maneuvers must be predicted using the detection data to estimate the position, speed and heading of individual targets. Conventional and adaptive beamforming algorithms are used to enhance the directivity and direction finding capability of a single sensor array and are essential in realizing the performance benchmarks required in detecting and localizing remote targets of interest. These spatial filtering methods allow position-related measurements such as bearing and range to a target to be computed from the steered response of an acoustic array.

One of the most challenging areas of the multisensor performance problem is the beam-pointing control of an acoustic array in dense multiple target environments, where closely spaced targets, highly maneuvering targets, and targets in the presence of multipath must be resolved. A variety of factors contribute to this problem including finite sensor resolution, beamshape, false alarms, complex target formations, and the non-stationary nature of target signatures. A project to study array signal processing techniques that would provide overwatch sentries with the ability to autonomously count the number of vehicles passing through a predetermined FOV was conducted in support of the RAPTOR program. In dense target environments, the detected acoustic signals are contaminated by the engine noise from other vehicles that are often louder than the target of interest. The problem of separating signals from individual targets in multiple target scenarios requires a robust adaptive approach to suppress interference from other vehicles closely spaced to the target of interest. The proposed solution to this problem is the design of an acoustic "trip-line" algorithm that addresses problems with the array's limited resolution due to its finite aperture, introduces noise suppression that excludes the undesired signals, and overcomes the inability to account for source motion.

Engineers at ARDEC have developed a target counting algorithm for the RAPTOR program that provides a means of discriminating and counting targets that pass through a sensor's predetermined field of view (FOV). This passive sensor approach samples acoustic emissions from ground vehicles using calibrated phased array microphones and employs advanced array signal processing techniques to discriminate between targets. The approach is made possible through an ACOE developed technique for high-resolution beamforming that provides enhanced sensor directivity by significantly reducing the effects of ambient noise or other signals outside the precise steering direction of the beams. The "trip-line" approach described in this paper utilizes both conventional and adaptive beamforming algorithms that realize a tapered beam pointing method and form a refined spatial filter that captures the harmonic content of individual targets that pass through a fixed line in bearing. The power from narrowband signal components in both the conventionally and adaptively formed beams is monitored so that a target crossing a line of bearing through one of the designated beams triggers the event of a target count. Conventional beamforming is used to "coarsely" filter and estimate the DOA of narrowband acoustic sources impinging on the circular array of microphones. The "fixed" beam pointing and highly selective spatial filtering is achieved using a minimum variance distortionless response (MVDR) beamforming algorithm in which the spatial filtering function is frequently updated in response to changes in the local environment. This adaptive weight computation ensures a beamformer response that approaches the theoretically optimum solution by reducing (and often canceling) the effects of interfering signals. The adaptive strategy accounts for movements in source direction by frequently updating the spatial characteristics of the array to obtain an optimal signal to noise gain in the direction of the target. The performance of the algorithm is ensured using signal processing methods that provide the capability of both detecting the presence of every vehicle that approaches an acoustic array and obtaining a highly accurate vehicle count in accordance with RAPTOR system requirements.

Initial performance measures for the algorithm tested using signature data collected during RFPI indicate successful discrimination of targets in convoys at ranges of up to 340 meters from the road. Results from the Area Denial test performed at Picatinny Arsenal between September 24 – September 28, 2001 showed that the algorithm performed with > 95% accuracy by spatially discriminating between multiple M1A1 tanks, an M113 APC and a HMMV when sensors were placed 50-100m from the closest point of approach (CPA). Convoys typically reached speeds of up to 30 mi/hr and maintained as little as 50 m spacing between neighboring vehicles.