SMARTEK SYSTEMS, INC.

Detecting Low Flying Aircraft Using Passive Acoustic Technology

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This paper proposes well known acoustic detection and tracking techniques applied to the issue of small, low flying or ground-based vehicles approaching and crossing the US boarders by flying or moving in such a manner as to avoid detection by radar or other means because of their small radar or visible light signatures. Two approaches are briefly discussed. The first is based on existing commercial products to augment the CBP Unattended Ground Sensors or to be fielded as stand-alone units. It is intended to be as unobtrusive in implementation as possible. The second approach relies on a lifting body (balloon) to raise the detection arrays into the air. This method increases the height of eye, potential detection and tracking range, and communication distances associated with the system. It has the additional advantage of being able to "look down" to potentially hear and track ground based vehicles with known acoustic signatures.

Issue: Low flying aircraft and other vehicles entering US airspace/land borders undetected by radar or other means.

Proposed solution: Use non-radar-based acoustic detectors along to "listen" to for incoming aircraft/motor vehicles and report via telemetry.

Recommendation: Provide the Customs and Border Patrol with additional non-radar based sensors able to detect and provide tracking information of small aircraft /slow moving loud vehicles to augment current surveillance efforts along US borders.

Discussion: Contraband smugglers use low flying ultra-light aircraft (ULA) to circumvent increasing border security measures along the US and Mexico border. Recognizing the threat, the DHS Office of Technology Innovation and Acquisition (OTIA) published bid # HSBP1010R0074 on March 4, 2011, requesting a capability for "the persistent detection and tracking of aircraft that fly across United States borders. The aircraft of interest are slow moving, fly at low altitudes, and have a small radar cross section." While written to be open to any technology, the RFP had specifications directed mostly at the use of radar-based sensing. The small radar cross-section make ULA difficult to acquire and track using current, conventional air search radar. High frequency radars providing higher resolution have a high life cycle cost, have topography limited line of site detection distances like air search radars, and are not covert. The pilots just fly very "low and slow" and at night to avoid radar and visual detection.

These ultra-light aircraft have a significant acoustic signature that can be exploited by low power and low cost passive acoustic detection equipment. By properly deploying and distributing passive acoustic detection stations, a very effective barrier along US borders to provide robust detection and rapid localization to facilitate tactical interdiction.

Approach Number 1: The U.S. Customs and Border Protection (CBP) uses devices called the Unattended Ground Sensor (UGS) to detect personnel and vehicles engaged in illegal activity along the U.S. Border. The DHS Science and Technology (S&T) Directorate, under the SBIR TOPIC NUMBER H-SB011.2-001 Low Power Tri-axial Acoustic Sensor, announced an interest "investigate and characterize a tri-axis acoustic sensor with sufficient array gain to provide significantly longer detection ranges than the equivalent omni-direction microphone systems provide for the targets in question, document its commercial viability, and capture as many of its pre-production and prototyping characteristics as possible" to augment these Unattended Ground Sensors ability to detect and track aircraft. Essentially, the requested technology is described by **US Patent #5,798,983**. The commercially available sensor, manufactured by SmarTek Systems, has been in existence since 1997.

The SAS-1 acoustic sensor was demonstrated to the FAA in 1998 to monitor a taxi-way at Phoenix Sky Harbor Airport. The FAA was seeking a method to augment both visual and radar surveillance along ramp "R" obstructed from the ATC view by terminal and parking facilities. The SmarTek Systems' SAS-1 arrays tracked both aircraft and service vehicles along Ramp "R" as a demonstration aimed at allowing ground controllers "visibility" of ramp traffic regardless of weather or lighting conditions. Previous use of video monitoring had proven unsuccessful during periods of fog and dust storms. A simple 2.4 GHz transmitter was connected to each array placed along the ramp. Ramp activity was continuously displayed in the control tower on a computer monitor. A report documenting this demonstration is available.

Many landing strips and runways exist *insid*e US borders which are by design suitable as landing areas for low flying aircraft. Aircraft may use such facilities under visual flight rules, even during non-working hours at night. Further, many abandoned airstrips, never manned or monitored in any fashion, remain fully capable of being used for emergency or illicit purposes. By deploying passive acoustic detection stations at these unmanned locations behind the border, the "Trip Wire" barrier defense in depth is formed to provide timely detection and reports. Like the Sky Harbor demonstration, the arrays in "listen only" mode with no detectable emissions would detect and track taxiing or low flying aircraft.

In 2009 and 2010, SmarTek Systems conducted controlled testing of ULA detection using their SAS-1 sensor. The production SAS-1 processing frequency band was changed from 6 KHz used for highway traffic monitoring to a lower frequency band centered at 2 KHz. The tests were conducted at an airport located in Maryland, using specified flight trajectories against a modern ultra light aircraft equipped with the most up to date quieting technology. Crossing flight trajectories (maintaining approximately 100 to 200 feet altitude) were used to observe and record real time detection results which could be used later to quantify the maximum detection range of the physically un-modified SAS-1. Initial test results during warm weather indicated detection ranges at 2 km. Tests during cooler weather indicated distances at least to 1.5 km could be readily achieved using a properly "tuned" and positioned array. (See figure at the end)

An event-based reporting system using small, distributed and concealed arrays to provide information while preventing compromise of the monitoring site is proposed. Upon detection of low flying aircraft, each location transmits time, bearing and bearing rate (track info) during the period the individual site holds contact. When no valid targets are held, communications stay quiet for emissions control and preserve batteries. As a target passes over the field, each sensor reports its individual contact information in a time stamped report. Given the geo-location of each sensor location, a target track is rapidly determined for localization of the target for prosecution.

These inexpensive, passive acoustic SAS-1 sensors have been successfully deployed along US Highways since 1997 to monitor highway traffic speed and usage data. Many are solar powered, wireless sites have been deployed from the Phoenix Basin to Upstate New York along the Canadian border to provide long term, 24/7 detection and reporting along the nation's highways. This domestically manufactured equipment is rapidly deployed and may be modified to further enhance covert use in border security arena.

Approach Number 2: Other approaches to exploiting acoustic energy are a bit larger in foot print operationally, but have a long history both in underwater and air-based detection. The signal processing required to support notion of attaching appropriately sized and fitted arrays from floating "balloons", ideally tethered to a ground anchor for recovery and re-use, is far easier in implementation the signal processing in a sensor such as the SAS-1. The approach is not overly covert, but does have the advantages that it would be able to "look-out" farther and down for both airborne and possible terrestrial vehicle detection. Additionally, the frequency range of interest is well known for motor vehicles and has been sampled as discussed above for some UL aircraft. The additional flexibility of additional array aperture or configurations due to the longer tether-based profile, and increased communications range from additional transmission height-of-eye, may prove to off-set is lack of covert nature. The systems should be far easier to deploy and retrieve than many portable radar-based solutions in remote areas.

The number of sensor stations, in this example the type of arrays held aloft and in place by a tethered balloon, needed for a given coverage area is dependent on the performance and capability of each acoustic sensor station. Consider the following examples which demonstrate approaches at each extreme for solving the same problem.

Case 1 Many Short Range Stations and Significant Field Level Data Fusion Processing

A station may comprise a single omni-directional microphone sensor with relatively simple processing capability (low gain and no directivity) giving no more than very short range proximity detection. This approach would require a large number of stations spaced very close together to avoid gaps in detection coverage. This approach would also provide little or no noise and interference immunity on its own. While this approach could be arguably the lowest power approach for station sensing and processing, it requires the most frequent communication of detection event data to a central processor to be combined with other neighbor station data for detection, association, localization, and tracking so as to remove false alarms and generate accurate aircraft trajectories.

Case 2 Few Long Rang Stations and Modest Field Level Data Fusion Processing

A station may comprise a significant acoustic array (number of elements and size) and with significant spatial and signal processing capability (power hungry hardware). Deployment would be more involved and the station would be much less covert. This station would provide much more array gain and directivity and result in much longer range detection. Wide area coverage requires significantly fewer of these stations. And because this station is highly directive it is more immune to local noise and interference. However, because of its long range detection capability, the potential exists for many more long range interferers to sort through. More inter-array correlation would be required. Since higher quality target detection, localization, and tracking information would be obtained at the station, much simpler and less frequent target information messages need be transmitted. One important aspect to consider is that the longer the detection range of the station, the more impact terrain and environment variation will come into play. Long range detection will definitely be limited by environment, surrounding terrain and obstacles. Also note that failure of a long range station leaves a much bigger gap in coverage.

Case 3 Use Medium Range Stations and a Moderate Field Level Data Fusion Processing

This approach is a trade-off between the first two approaches. A smaller acoustic microphone array is used with beamforming and adaptive spatial processing to gain the benefits of array gain for increased range, directivity for local interference immunity and target bearing estimation without the ill-effects that source-receiver relative motion causes for cross-correlation processing, Additionally, the spatial processing provides valuable bearing rate information for location and false alarm reduction (as in the bearing/bearing rate consistent with aircraft approach). Medium detection ranges also are not impacted a much by terrain, obstacles, or environmental conditions. In short, the array design, processing frequency band, and other physical considerations can be determined to optimize cost, performance, ease of deployment, power requirements, and communication requirements.

In simple terms, the trade-off becomes one of using large numbers of closely spaced proximity sensor stations requiring frequent communication of detection events and significant “field level” processing in a central processor or using fewer widely spaced sensor stations employing advanced adaptive spatial processing to get large aperture performance (gain and directivity) from a small aperture with capability to provide quality target trajectory information and requiring less frequent communication and much simpler central processing.

This problem is not new. There is a very large and significant body of work that has been established and evolved over the last several decades in the area of underwater acoustic processing for submarine detection and Anti-Submarine Warfare (ASW). The trade-offs and evolution between long range detection and tracking and short range sensor field level detection and tracking has been ongoing for the ASW development community for decades. The notional sonobouy field scenario at the end illustrates an example of case 3 deployment of acoustic sensors from “balloons.” While the target/receiver relative motion dynamics are different, the areas of processing for both broadband and narrowband target signatures are the same for acoustic detection and tracking of low flying fixed wing aircraft, or ground based vehicles if a look down sensor position is provided, as that for acoustic detection and tracking of ships and submarines in the ocean. These areas include the following:

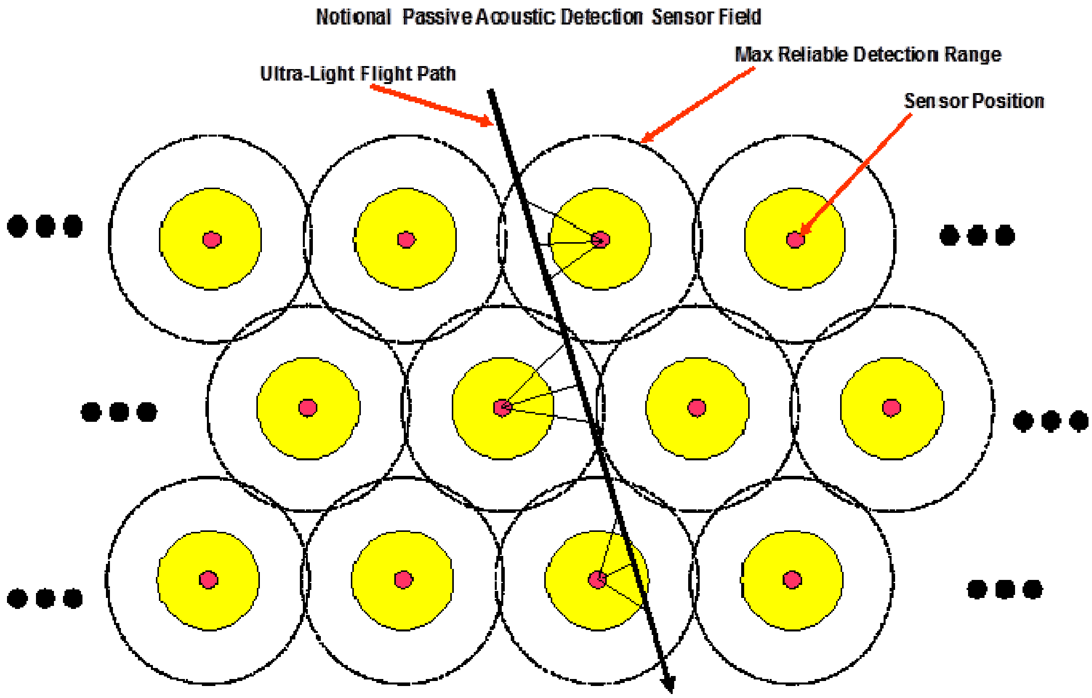
1) Sound propagation and modeling
2) Sensor Array signal conditioning and sampling
3) Beamforming, adaptive spatial processing, and spatial normalization

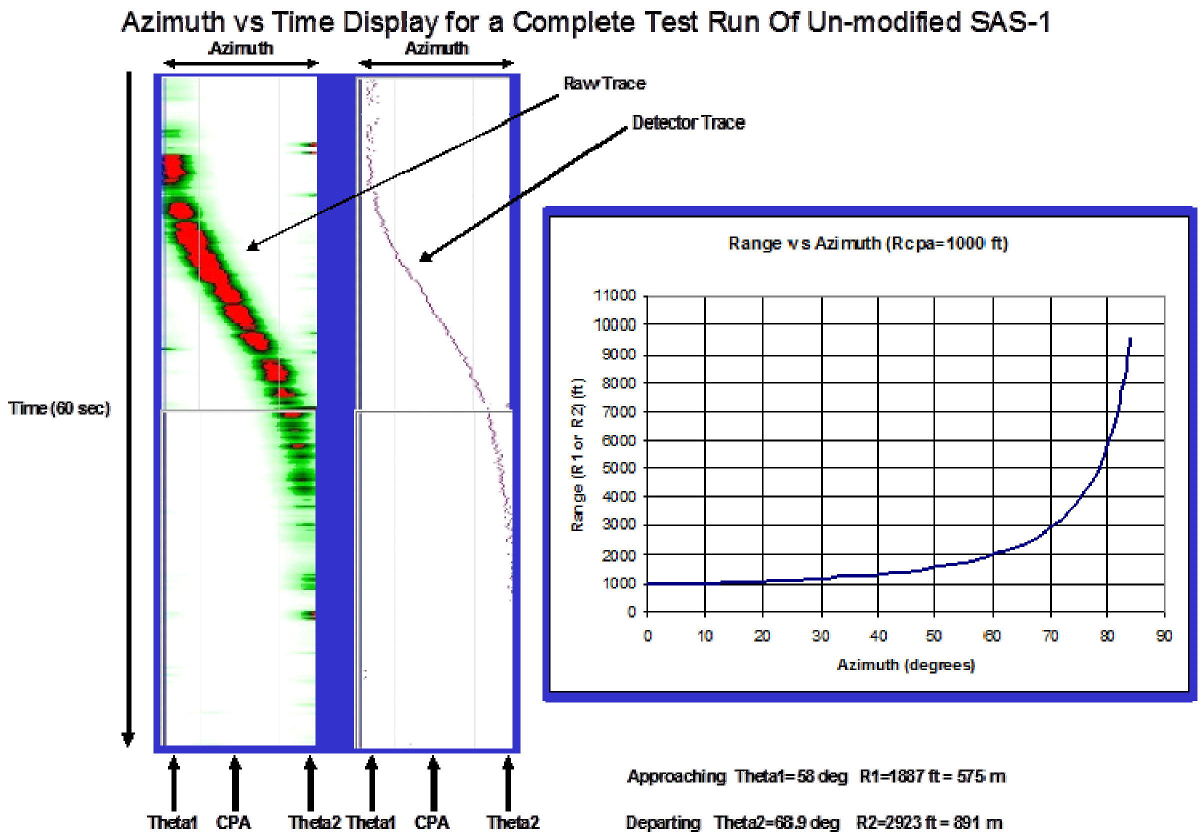
4) Spectral analysis, spectral normalization, and classification based on acoustic source harmonics
5) Detection and measurement tracking (bearing, elevation, and frequency)
6) Localization and target state estimation (snapshot and temporal based)

The SmarTek Systems' passive acoustic traffic sensor (SAS-1) represents an example of utilizing undersea acoustic spatial and signal processing technology expertise to develop, produce, and sell a highly capable and reliable multi-lane highway traffic sensor in a widely dynamic target detection and tracking scenario. This expertise will be utilized to investigate and demonstrate capability and performance trade-offs to arrive at a viable high performance and cost effective system for rapidly detecting, tracking, and reporting the presence and state of a low flying fixed wing aircraft or motor vehicles from the vantage point deemed necessary by the CBP.

Areas of investigation include:

1) Investigate microphone array design and adaptive spatial processing and Frequency Band.
    - Increase detection range via array gain against increased detection range via processing lower frequency broadband and narrowband components.
2) Investigate sensor placement above the ground to facilitate multipath range/elevation estimation
    - Placing sensor above the ground facilitates measurement and use of near in surface (ground) reflections correlated with direct path (very similar to multipath utilization in underwater acoustics)
3) Investigate effectiveness of various localization approaches including single sensor approaches like bearing-doppler narrowband ranging and multi-sensor cross-fixing.
4) Investigate array/sensor arrangement and processing to measure elevation angle.
    - Non-coherent interpolation between multiple vertical beams
    - Coherent cross-correlation between azimuth beam and vertically separated microphone
5) Investigate different power saving (standby modes) for processing HW and microphone array
    - Observation duty cycle (process for detections at some interval i.e. turn on and process every 5 sec instead of continuous until detect then process a normal rate)
    - Use only few microphones to monitor low frequency then turn on all HW for processing





Raw data recordings showing acoustic signature of a typical Ultra-Light Aircraft inbound from a range starting >2000 ft to a closest point of approach of near 1000 feet, along with the louder (darker with more red color in the trace) departing signature recorded by the sensor.