

# *Wireless Sensor Networks for Localization and Tracking of Acoustic Sources*

**People:** Prof. Mahmood R. Azimi, Project Leader, e-mail: [azimi@engr.colostate.edu](mailto:azimi@engr.colostate.edu)

Nick Roseveare, M.S. Student, e-mail: [nrosev@engr.colostate.edu](mailto:nrosev@engr.colostate.edu)

**Sponsor:** Information Systems Technologies Inc. (ISTI) under US Army SBIR program.

## **Objectives:**

Over the years, sensor array processing techniques have become more essential for battlefield and situational awareness. Current applications include but not limited to acoustic detection and localization of different ground and airborne sound sources, and radar and sonar target detection and tracking systems. The systems for our specific application are made up of passive acoustic sensors and are meant to be left in the field unattended. Unattended ground sensors (UGS) fulfill a variety of military applications including battlefield surveillance, situation awareness and monitoring. They are rugged, reliable, and can be left in the field for a relatively long period of time after deployment. They can be used to capture acoustic signatures of a wide variety of sources including ground vehicles, airborne targets, acoustic transients such as gunshots, or personnel in urban areas. The use of wireless acoustic sensors provides the possibility of forming dynamic array configurations whose diverse structures help to mitigate the effects of sensor position errors and correlated fading on the performance of the direction of arrival (DoA) estimation [1] and transient event localization [2]. However, there are other issues related to information transfer, e.g. packet scheduling, power management, multi-channel wireless data processing, as well as determining the sensor positions using self-localization methods that must be addressed.

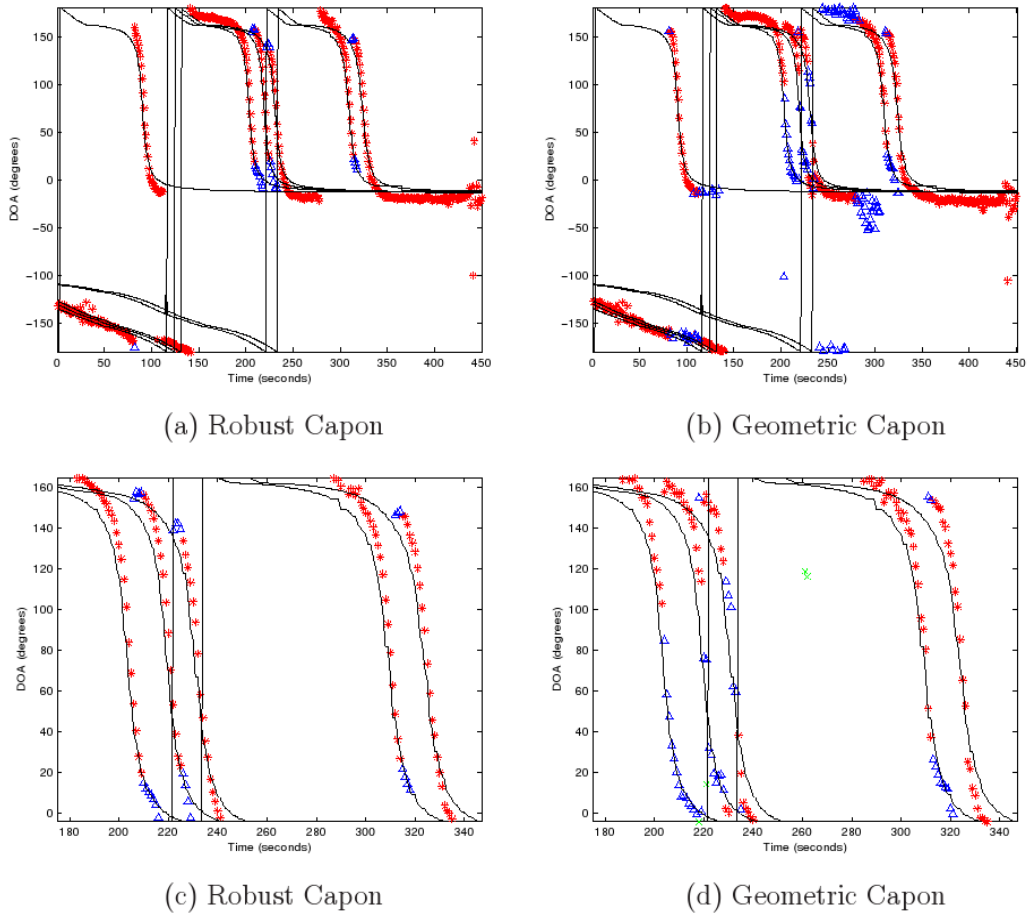
The problem of detection and localization of multiple ground sources using unattended acoustic sensors is complicated due to various factors. These include: variability and non-stationarity of acoustic source signatures, signal attenuation and fading effects as a function of range and Doppler, coherence loss due to environmental conditions and wind effects, near-field or multipath effects, other non-plane wave effects due to array geometry or calibration errors, and a high level of acoustic clutter and interference. In addition, the presence of multiple closely spaced sources that move in tight formations further complicates the detection, DoA estimation, data association, and localization processes.

In this work we have developed a new robust wideband DoA estimation method to account for the inherent uncertainties in the array steering vector. Also, to improve the resolution within an angular sector of interest and to provide robustness to sensor data loss, the beamspace method [1] was extended and applied to the wideband problems. These methods were then tested and benchmarked [4],[5] on two real acoustic signature data sets that contain multiple ground vehicles.

## **Results:**

The wideband DoA estimation algorithms developed in this study were first applied to the data collected using a 5-element wagon-wheel circular array [4],[5] each with 2 ft radius. The collected data had to be calibrated prior to DoA estimation in order to account for the inherent errors between the ideal values of the array parameters, namely microphone gain and phase as well as sensor positions, and the actual values of these parameters for the deployed arrays. Figures 1(a) and 1(b) show the DoA

estimation results using robust wideband Capon method versus the original wideband geometric Capon on a run with six moving vehicles. The vehicles consisted of both light and heavy wheeled or tracked. This data set is used to demonstrate the usefulness of the proposed methods for resolving multiple closely spaced sources. The robust Capon was applied to the uncalibrated data. Figures 1(c) and 1(d) show the close-up of the same results in time segment of 180-240 seconds. It is clear that the robust Capon method provided much more accurate DoA's especially when the targets are close to the sensor array (near-field effects).



*Figure 1: Results using the robust wideband Capon and original geometric Capon methods. Improvements are especially noticeable in the near-field regions which are enlarged.*

In the second experiment, we used a data set collected using a distributed wireless acoustic sensor network consisting of 15 nodes. Figure 2 shows the random pattern of deployment for this sparse array. This data contains acoustic signatures of one or two light wheeled vehicles. This data set was used to show the promise of the wideband beamspace method in presence of sensor failure or corrupt sensor data. For the beamspace Capon we used 3 beams spaced at  $-6$ ,  $0$ , and  $+6$  degrees from the look direction.

During the data collection some sensors failed to collect reliable data because of either bad microphone, or amplifier circuit, or both. To account for sensor failure in the DoA estimation process, one has to screen the data and manually remove the failed data channels before beamforming. This precludes real-time DoA estimation. To demonstrate the usefulness of the wideband beamspace method in these situations, this method was employed here without using the knowledge of the failed sensors or their numbers. Figures 3(a) and 3(b) show the DoA estimation results of the beamspace and original

wideband geometric Capon methods on a run with one failed sensor. Figures 3(c) and 3(d), on the other hand, show the results using the robust Capon and the weighted subspace fitting (WSF) method [1] on the same data set. As can be seen, even in presence of the failed sensor data the DoA estimation results of the beamspace Capon are much more accurate than those of the original wideband Capon when the bad sensor data was manually removed.

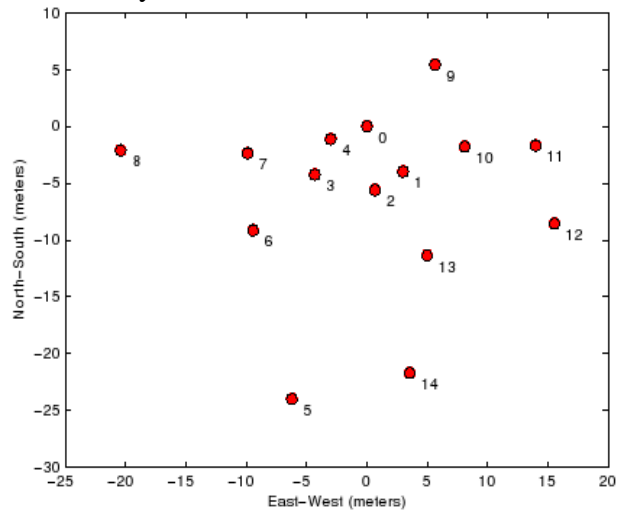


Figure 2: A randomly distributed wireless sensor network.

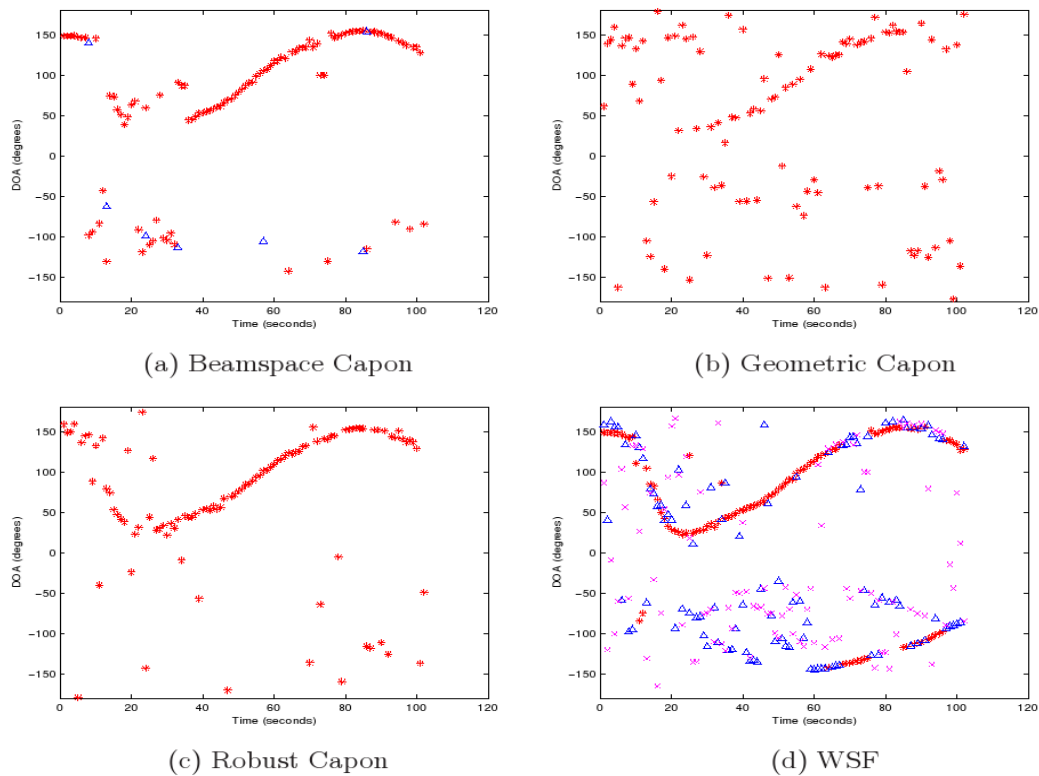


Figure 3: Comparison of beamspace and robust Capon methods with the original geometric Capon and WSF methods.

## **Future Work:**

Future work will focus on using the estimated DoA's to perform multiple vehicle localization using data association and Maximum Likelihood (ML)-based [2] methods. Additionally, it would be desirable to track the moving vehicles especially when they are spatially close together.

## ***Publications:***

- [1] Van Trees, H. L. *Optimum Array Processing*. New York: Wiley Interscience, 2002.
- [2] Y Jiang and M.R. Azimi-Sadjadi, "A Robust Source Localization Algorithm Applied to Acoustic Sensor Networks", *Proc. of 2007 IEEE Inter. Conf. on Acoustics, Speech and Signal Processing (ICASSP'07)*, Vol. 3, Honolulu, HI, April 2007.
- [3] Li, J., Stoica, P., and Wang, Z. On robust capon beamforming and diagonal loading. *IEEE Transactions on Signal Processing*, vol. 51, pp 1702—1715, July 2003.
- [4] M. R. Azimi-Sadjadi, A. Pezeshki, and N. Roseveare, "Wideband DoA estimation algorithms for multiple moving sources using unattended acoustic sensors," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 44, pp. 1585-1598, October 2008.
- [5] M. R. Azimi-Sadjadi and N. Roseveare, "Robust beamforming algorithms for acoustic tracking of ground vehicles," in *Proc. of SPIE'06 Defense and Security Symposium*, vol. 6231, Apr. 2006.