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MEMS Acoustic Sensor for UAV Detection and Localization

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NPS NRP Executive Summary

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Report Date: 10/14/19 Project Number (IREF ID): NPS-19-N080-A

Naval Postgraduate School / School: Graduate School of Engineering and Applied Sciences

NAVAL RESEARCH PROGRAM

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MEMS ACOUSTIC SENSOR FOR UAVE DETECTION AND LOCALIZATION

Period of Performance: 10/15/2018–10/15/2019

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Topic Sponsor Lead Organization: US Fleet Forces Command (USFF)

Topic Sponsor Name: Science Advisors, Commander, Submarine Force (COMSUBPAC), U.S. Pacific Fleet, Mr. Nick Frade, Mr. Ray Harnois and Mr. Stephen Turner

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EXECUTIVE SUMMARY

Project Summary

The proposed one-year research effort was to explore the feasibility of using microelectromechanical systems (MEMS) acoustic sensors to detect and localize unmanned aerial vehicles (UAVs). The detection and localization scheme is based on the hearing organ of the parasitic fly *Ormia ochracea*, which performs a signature-based detection of chirping crickets. In order to do that, we studied and analyzed acoustic signatures of available UAVs to identify common spectral tones used for modeling, simulation and theoretical evaluation of the sensors. The *Ormia*-based MEMS sensors are around 50 times smaller than the sound wavelength they detect, and the final system including electronics would be smaller than a square centimeter. They can exhibit greater signal-to-noise ratio and directional response than currently available broadband microphones. Preliminary results indicate a great potential for this type of sensor to be used as an aid for counter UAV operations.

Keywords: *microelectromechanical systems sensors, MEMS sensors, unmanned aerial vehicle, UAV, acoustic signature, sound detection directional acoustic sensors*

Background

When compared with the electromagnetic counterparts, acoustic sensors have many advantages in detecting drones: non-line-of-sight, passive, low-cost, low-power, light, and small. Acoustic sensors are the primary sensors employed in most unattended ground sensor systems because they can provide detection, direction finding, classification, tracking, and accurate cueing of other high-resolution sensors (Srour & Robertson, 1995). They are equally effective against continuous and transient sound sources. Recently, the skyrocketing small flying UAV technology has pushed the sensor field towards the characteristics that match the spectrum of sound sensors.

The motivation for this research is to localize sound sources with sensors much smaller than the wavelength they detect and without the need of complex array arrangements (Letowski & Letowski, 2012; Miles, Robert, & Hoy, 1995). One attractive way is to use MEMS sensors based on the parasitic fly *Ormia Ochracea*. This parasitic fly has developed a unique approach to direction finding, and it is able to localize chirping crickets with remarkable accuracy. Miles et al. (1995) found that the two eardrums of the fly are mechanically coupled and have two natural resonant frequencies. The fly employs the coupling between the two modes to sense a sound's direction, making use of the unequal vibrational amplitudes of the two eardrums (Wade & Deutsch, 2015).

Our research group has a legacy know-how on *Ormia*-based detectors (Touse et al., 2015; Downey & Karunasiri, 2013; Wilmott, Alves, & Karunasiri, 2017). The sensors can be tuned by design to be sensitive to specific spectral features (specific tones) while filtering out all undesirable acoustic bands. Previous studies of the sensor showed high directional accuracy (less than 2 degrees for single tone and less than 4 degrees for sound bursts, such as gunfire).

Preliminary studies with small flying UAVs indicate they exhibit unique spectral features that the MEMS sensors could be employed to detect. *Ormia*-based sensors can exhibit a greater signal-to-noise ratio than currently available broadband microphones, and directionality can be achieved with a single sensor.

In this context, we hypothesized that MEMS sensors can be effectively used to detect and localize UAVs. The study explores a novel application for a successfully developed MEMS directional acoustic sensor by modifying its spectral response (by design) to perform signature-based detection.

Findings and Conclusions

We have selected specific sound frequencies for UAVs, based on their acoustic signatures, and studied the response of customized MEMS sensors against flying targets in a controlled environment and an open field. The data was collected to assess the performance of the sensors and compare it with conventional microphones. The ability to effectively provide awareness, detection and localization of the acoustic sources on the soundscape could allow immediate countermeasures towards threats or cooperative operation with partner platforms. These capabilities, obtained by miniature sensors with minimal impact on the internal signal processing and computational resources and power budget, could signify a tremendous source of operational asymmetry.

On one hand, the conducted feasibility study of miniature acoustic directional sensors for UAV localization directly addresses the requirements specified by the Sponsor: (a) low cost; (a) small form factor; (b) low power consumption; (c) greater detection range than available solutions; and (d) single sensor directionality. Such characteristics could be helpful for applications in battlefield environments and eventually allow for employment of networked distributed sensors in order to triangulate and track flying UAVs.

On the other hand, this study allowed the expansion of the know-how of the sensor operation theory: the impact of environmental conditions such as humidity, wind gusts, dust, and background noise on the sensor performance. In addition, we gained a greater understanding on the acoustic signatures of the sources intended for detection (UAVs) and their environment of operation, allowing for more efficient future study cycles.

During the initial phase of research, Naval Postgraduate School students from the Physics and Systems Engineering departments recorded and studied acoustic signatures of several UAVs. Cross spectrum, cross correlation, and other analysis techniques were used to find the specific spectral features that tailored the MEMS sensor optimum response. This was performed across several flight regimes of a single drone and across several small flying UAVs.

Next, using finite element modeling, we studied the MEMS sensor performance optimized to the perennial frequencies found during the acoustic signature analysis. The newly developed sensors were tested in an anechoic environment and on the field. Their performance compared with current acoustic detection systems. Directional response accuracy of localization was tested utilizing multiple sensors in the field. Finally, the readout and signal processing electronics were studied and optimized to provide maximum performance in detection range.

Initial results indicate that our *ormia*-based MEMS sensors could outperform available high-end microphones in two categories: detection range and directional accuracy.

Recommendations for Further Research

It is important to highlight that the *Ormia*-based acoustic sensors have been studied in the past decades; however, they never left the research laboratories. Designing, tailoring and optimizing them for specific applications is intrinsically novel and will require a few more cycles of studies. The future work should encompass the expansion of the single sensor capability for a network arrangement of distributed sensors that can be potentially used for 3-D localization and tracking of the intended acoustic sources. New demodulation techniques must be investigated to improve performance as well as sensor ruggedizing for field operation.

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Acronyms

Microelectromechanical Systems	MEMS
Unmanned Aerial Vehicles	UAV