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Analysis of MEMS-based Acoustic Particle Velocity Sensor for Transient Localization

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14. ABSTRACT
The U.S. Army Research Laboratory (ARL) has made tremendous progress in the area of acoustic target tracking. Current systems are reliable and provide actionable situational awareness, but they are often bulky. In an effort to reduce size, weight, and power, ARL has evaluated the feasibility of replacing our current acoustic sensor with a three-dimensional (3-D) acoustic particle velocity sensor based on micro-electro-mechanical systems (MEMS) technology. This sensor has the potential to simplify sensor setup and maintenance, as well as reduce the computational requirements of the signal processing software. This effort validates specified frequency response, identifies sensor limitations and capabilities, and quantifies sensor localization accuracy. Experimental results conducted in both ARL's anechoic chamber as well as outdoor environments are analyzed.

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Acoustics, localization, MEMS, particle velocity

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Contents

List of Figures

1. Introduction

In an ongoing effort to reduce size, weight, and power, of current acoustic target tracking systems, the U.S. Army Research Laboratory (ARL) has evaluated the feasibility of replacing acoustic sensors with a three-dimensional (3-D) acoustic particle velocity sensor based on micro-electro-mechanical systems (MEMS) technology. This report presents a number of tests of the Microflown sensor, performed at ARL, which have focused on the sensor's accuracy in determining the direction of small caliber fire. The focus of earlier articles by de Bree, Wind, and others (*1*) has been on outlining possible applications, with limited sidesteps to experimental results. This report presents a large amount of experimental data and attempts to evaluate the strengths and weaknesses of the sensor.

This report is built up as follows. The specifications of the sensor are considered in section 2. Section 3 goes over the experiments and the experimental results. In section 4, the report is summarized and conclusions are drawn.

2. Sensor Specifications

Microphones respond to acoustic waves by generating an electrical signal when a diaphragm vibrates in response to fluctuating air pressure. In contrast, the Microflown sensor, developed by Microflown Technologies, measures the velocity of air across two tiny, resistive strips of platinum that are heated to 220 °C. In acoustics, this movement of air is termed *particle velocity*. When air flows across the strips, the first strip cools down a little, and due to heat transfer, the air picks up some heat. Hence, the second strip is cooled down with the heated air, but cools down less than the first wire. A temperature difference occurs in the wires, which causes a difference in their electrical resistance. This causes a voltage difference that is proportional to the particle velocity and the effect is directional: when the direction of the airflow reverses, the temperature difference will reverse too. In the case of a sound wave, the airflow across the strips alternates in conjunction with the waveform and thus the corresponding alternating voltage (*2*).

The self-noise of the Microflown sensor is –10 dB√Hz at 1 kHz, where 0 dB√Hz is the threshold of hearing (*3*). Nonlinearity is estimated to occur around 135 dB (*3*). The elements have been tested successfully in a wide temperature range, from –78.5 to 300 °C. A weakness of the Microflown sensor is its sensitivity to wind. Without wind caps, the standard probes are limited to 2 m/s, which definitely is not sufficient for outdoor conditions. The basic wind protection used in this report extends the range to about 10 m/s. Improved wind protection for the Microflown sensor is a topic of ongoing research.

The Microflown Ultimate Sound Probe (USP) (figure 1) is an *acoustic vector sensor* (AVS). It contains a pressure microphone as well as three Microflown elements that are sensitive in perpendicular directions. The *sound intensity* vector is obtained by multiplying the scalar pressure by the particle velocity vector. This vector points away from the acoustic source, such that the direction of the source can be determined for every sample of incoming data with very little processing. The direction of arrival can be determined from 10 Hz to 10 kHz (*3*), which is wider than most other systems.

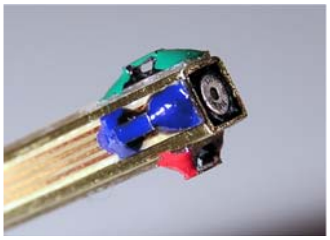

Figure 1. Microflown USP.

3. Experimental Procedures

Initial evaluation of the Microflown sensor was conducted in ARL's anechoic chamber and various outdoor environments (with and without windscreens). The overall objective was to verify the specified frequency response, identify sensor limitations and capabilities, and quantify sensor localization accuracy.

Figure 2 corresponds to data acquired in the ARL anechoic chamber. The sensor was mounted on a pan-tilt unit and rotated clockwise 360° with increments of 10°. A stationary transient sound source was located at the 0^{th} position of the pan-tilt unit approximately 6 in away. Outliers centered around 0° are believed to be a direct effect of the internal motor on the pan-tilt unit. Results for elevation estimates, seen in figure 3, proved to be inaccurate and less consistent. As a result, elevation estimates for the outdoor experiments were not presented.

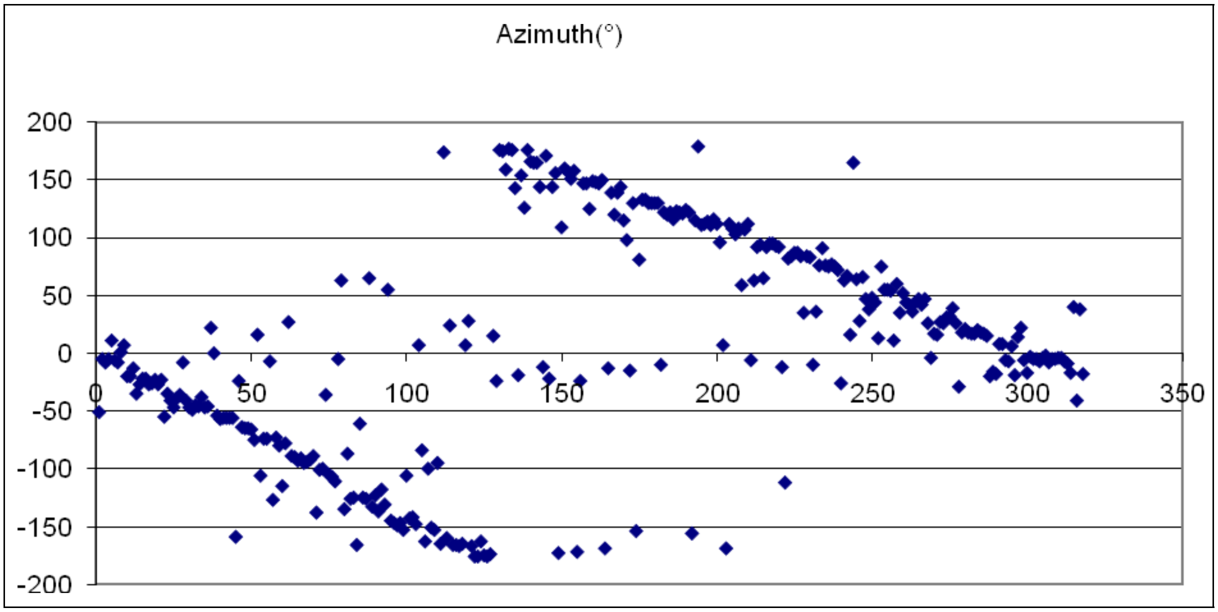

Figure 2. Microflown azimuth estimates; data taken in the anechoic chamber.

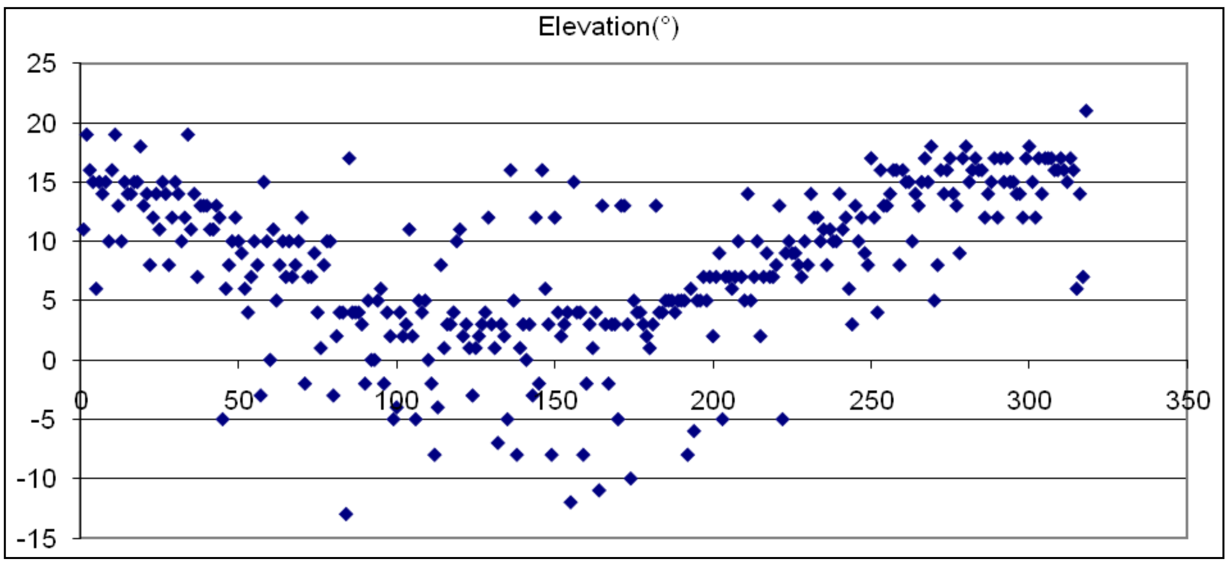

Figure 3. Microflown elevation estimates; data taken in the anechoic chamber.

The next experiment was conducted outdoors with a propane cannon and impact hammer as the transient targets of interest. The propane cannon was moved to six different locations, indicated by p_1–p_6, over the duration of the test, with the furtherst location approximately 1 km away. It should be noted that the transient sources were located in a building structure for scenarios 5 and 6. Figure 4 is a cartoon illustration, not drawn to scale, of the various firing positions for this field experiment.

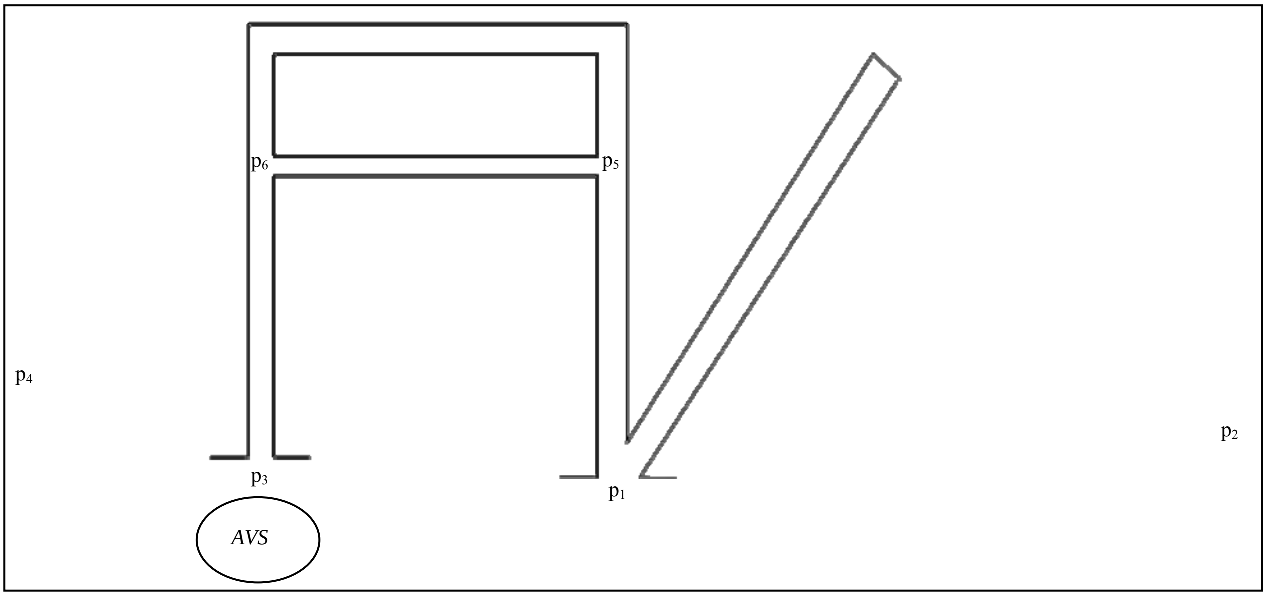

Figure 4. Firing positions for propane canon.

Figure 5 contains a sample of unprocessed data of the Microflown AVS for one scenario mentioned above.

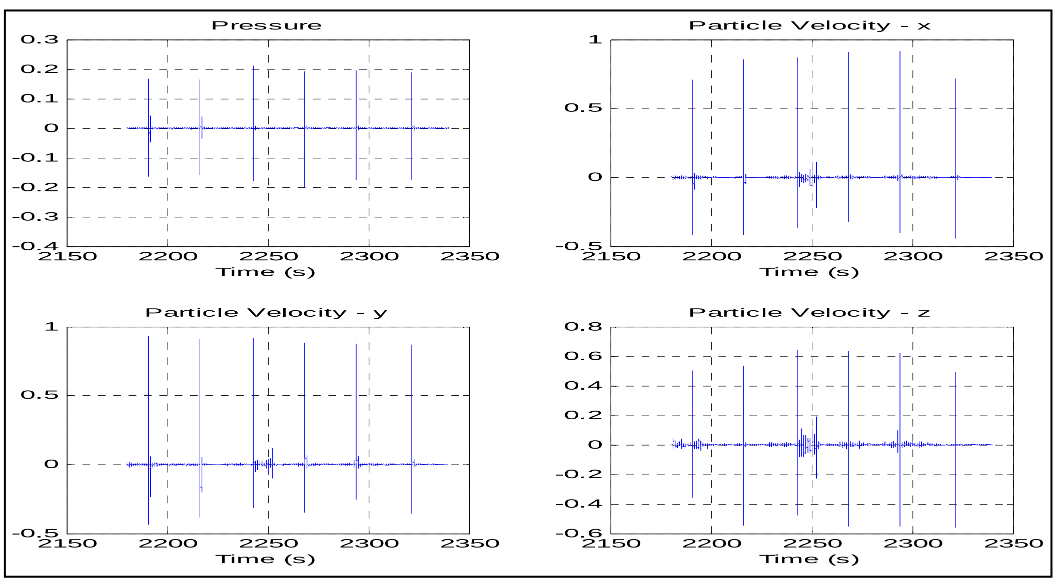

Figure 5. Unprocessed data of AVS.

Figure 6 is a plot of the truth data associated with the target locations versus that of the estimated azimuth from the Microflown senor. The truth data and estimated results are represented by the squares and diamonds, respectively.

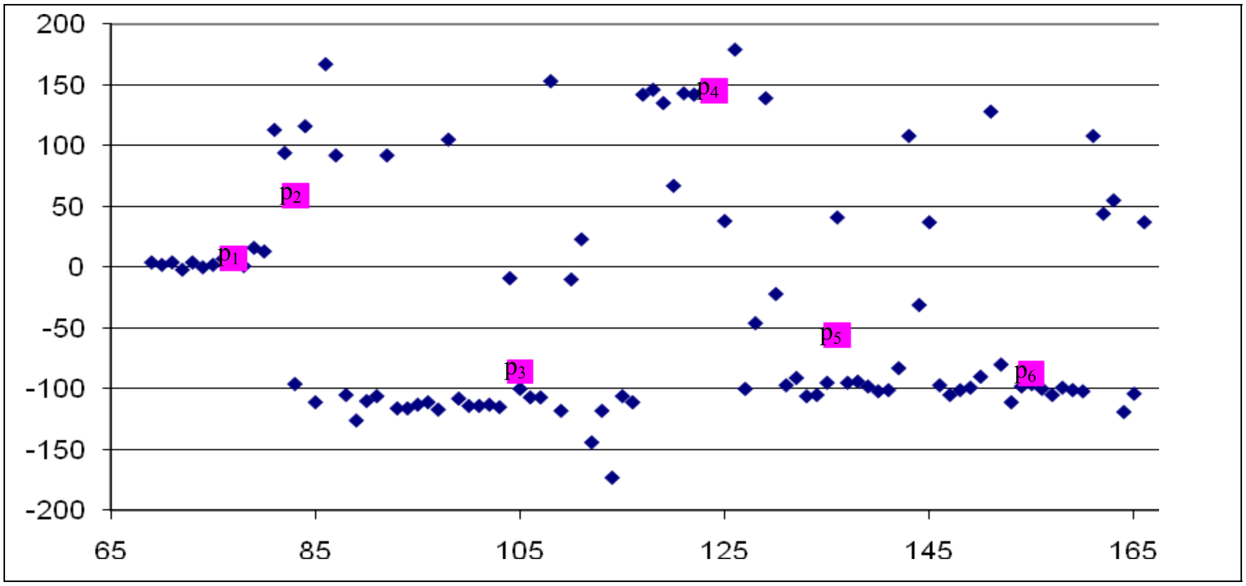

Figure 6. Microflown localization results associated with propane cannon and impact hammer.

For scenarios 1, 3, 4, and 6, the sensor performed fairly well at localizing on the target of interest with an approximate standard deviation of 6°. In scenario 2, where the distance from the sensor to the target was 1 km, accurate target tracking was impossible due to terrain features. Finally, scenario 5 appears to have poor results; however, it should be noted that the system consistently points in the same general direction of p_6, that of the nearest opening, which is more than likely the direction of the loudest transient sound. Spurious detections can be attributed to nearby sound sources such as the closing of car doors.

The sensors are currently manually aligned toward some known aiming point. It is highly likely that a bias is introduced in the azimuth and elevation calculations each time the sensor is aligned. Ideally, the sensor should be equipped with an inertial sensor to provide a more accurate heading reading.

Figures 7 and 8 contain data from a live-fire experiment in a highly reverberant environment as the shooter fires the same weapon from two different locations. Analysis of both figures indicates a bias of approximately 2° and 7°, respectively, again thought to be related to alignment, as well as reverberation from a nearby structure. The shooter's actual position is identified by the square and the estimated position with a diamond. The standard deviation of the estimated shooter location is approximately 0.3°.

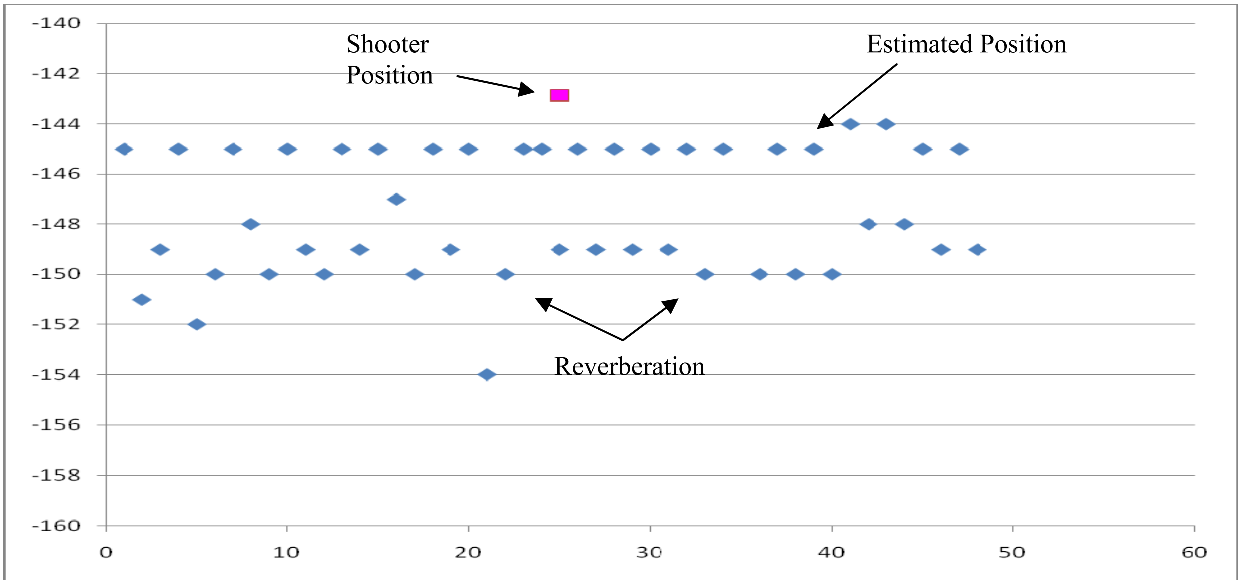

Figure 7. Microflown localization results M9 5-round bursts; shooter position 1.

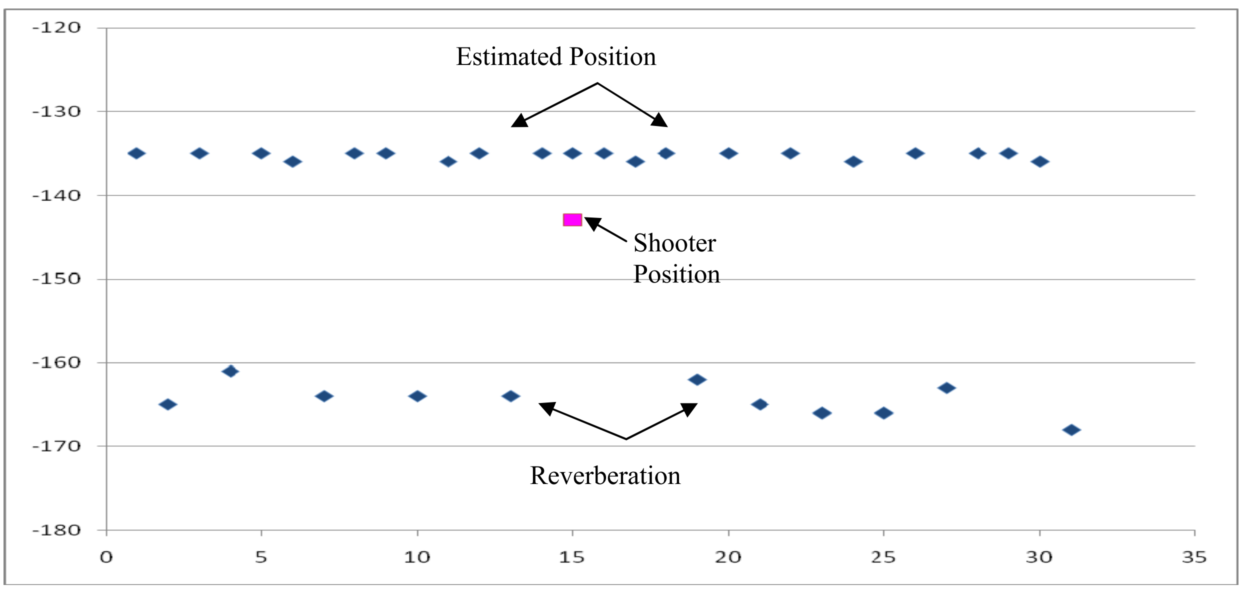

Figure 8. Microflown localization results M9; shooter position 2.

4. Conclusion

The Microflown sensor has verifiable application to both transient detection and broadband tracking applications. This technology will allow for fewer, lightweight, low-power deployed systems. These sensors can also potentially eliminate the need for computationally intensive signal processing techniques. One limitation is the sensor is sensitive to environmental effects such as moisture and dust. As a result, additional engineering to the packaging of the sensor is necessary prior to prolonged fielding of sensor. Other areas of future work include improving the elevation estimation either by modifying existing hardware or compensating for errors via software corrections, and developing intelligent signal processing techniques to eliminate reverberation. Wind noise may also pose a threat by degrading a signal of interest, particularly when it comes to signatures within the infrasonic range. Finally, an interesting and important topic of future research is to determine if the Microflown sensor can be used to resolve multiple simultaneous targets.

5. References

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