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Tracking Targets of Interest Via Acoustics

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14. ABSTRACT

Current military operations require robust signal-processing algorithms that allow for hostile fire defeat in reverberant environments. These algorithms must provide the individual Soldier with real-time situational awareness and actionable intelligence. Sensor configuration, terrain features, and atmospheric conditions must be considered when one is developing such algorithms. This report analyzes localization results of a novel signal-processing technique used to localize and track acoustic mortar data during a recent field experiment.

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Summary

Tracking targets of threat is of vital importance to the success and survival of military personnel during times of war. This same information is crucial in reducing civilian casualties and capturing insurgents. Acoustic signatures of live fire mortar data are used to analyze the performance of a simple tracker algorithm and improve current accuracy. This research has proved that the algorithm provides good results when the sensors and targets are within a few kilometers of each other. It is recommended that future localization algorithms account for atmospheric and terrain conditions in an effort to increase overall system accuracy.

1. Introduction

Acoustic sensors can provide a wealth of information for the individual Soldier. These devices, accompanied by novel signal-processing algorithms, are useful in locating the point of origin and point of impact of hostile fire. Knowledge of this information increases overall situational awareness (SA), allows for possible return of fire, and triage in a timely manner. Localizing on impulsive events becomes challenging when one is operating in less than ideal atmospheric and terrain conditions. Some sounds will be masked while others will be produced because of reverberation and multipath. In this report, we study algorithms that estimate acoustic event location based on measurements of time of arrival (TOA) and direction of arrival.

Current military operations require robust signal-processing algorithms that allow for hostile fire defeat in reverberant environments. These algorithms must provide the individual Soldier with real-time SA and actionable intelligence. Sensor configuration, terrain features, and atmospheric conditions must be considered when one is developing such algorithms. This report analyzes localization results of a novel signal-processing technique used to localize and track acoustic mortar data during a recent field experiment.

2. Signal Processing

For a typical tracker, the data association problem is often complex. New reports continuously arrive and change the context in which previous decisions were made. Older reports lose relevance, and the tracker must run indefinitely as new targets come and go. Searching for a good hypothesis to explain the most recent reports is important, but the tracker must also remain poised to re-evaluate past decisions in the context of new information. The tracker to be analyzed uses the genetic algorithm (GA) to search for the best hypothesis over a sliding window of time. This technique has been simulated as part of a simple tracker that uses an alpha/beta filter for track prediction and a cost function based on the smoothness of track trajectories (*1*).

This method is ideal when one is trying to solve a problem for which little is known. GAs use the principles of selection and evolution to produce several solutions to a given problem (*2*). This program receives line of bearing (LOB) reports from a distributed network of sensors and fuses them to form tracks on the detected targets. The tracking algorithm evaluates the lines of bearings and where they cross to determine whether the detections are likely to be acoustic signals, and if so, plots an icon over the crossing. Next, the algorithm attempts to estimate how many targets there really were and their expected positions.

The algorithm then uses a least square estimate to minimize the angular distance (i.e., how much does the LOB generated from the sensor miss the cross point), given 1 second of data. Finally, the time cost is computed by subtraction of the estimated TOA from the actual time of arrival. The tracks that fall within both constraints are kept and all others are discarded. Only the final updated solution is used in our analysis even though this may not be the most accurate solution. The decision to process the data as such is partly because the inexperienced user assumes that updated tracks increase accuracy as additional information is received.

An alternative to the previous algorithm would be to implement a maximum *a posterior* (MAP) estimator for noisy measurements. It formulates the problem as that of a multiple hypothesis testing. This test can be done optimally, in the sense of minimizing the probability of picking the wrong hypothesis, by the m-*ary* maximum *a posteriori* probability decision rule. In our case, the parameters for the probability distributions are unknown. However, if one can replace them by their ML estimates, a decision can still be made, based on their corresponding ML values. In this implementation, a search is conducted over all partitions of main/multipath observations (within each subset) for the most likely one. This operation is combinatorial but is much smaller than a full combinatorial search over all subsets of a hypothesis and over all hypotheses (*3*). Previous research has shown that this algorithm produces excellent results when one is analyzing acoustic data in reverberant environments.

3. Experimental Results and Procedures

Mortar data of different caliber (60 mm, 81 mm, 120 mm) and charge as well as simulated data via a propane cannon were collected during a recent field experiment. Acoustic sensors along with novel signal-processing algorithms were used to estimate the location of the varying gun position. Figure 1 maps the acoustic sensors with respect to the gun positions.

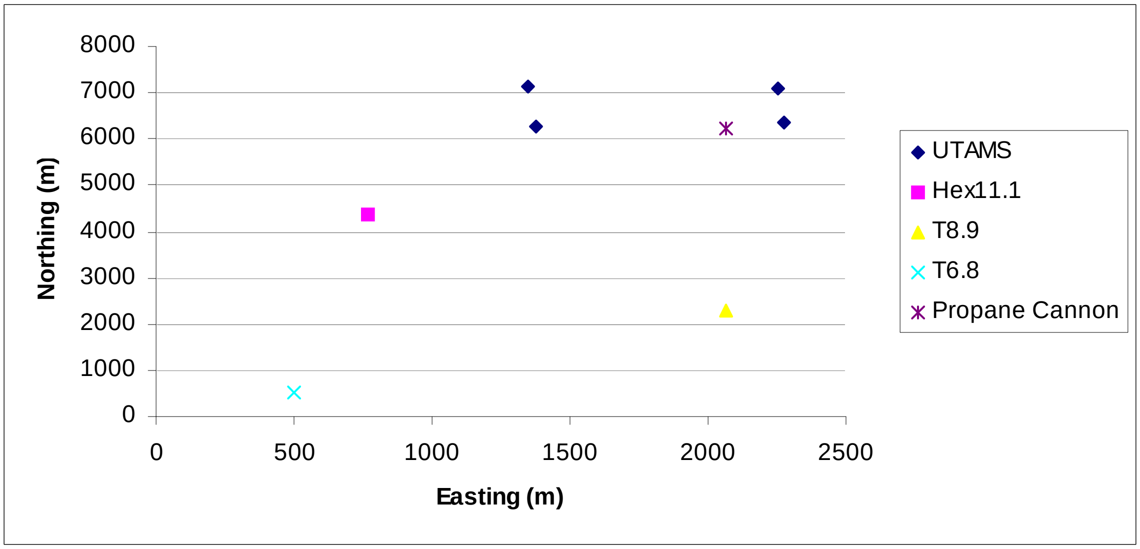

Figure 1. Acoustic sensors and gun locations.

Figure 2 illustrates the results taken from gun position Hex 11.1 where the calculated launch position is plotted against the actual. With the exception of a few outliers, the algorithm was able to localize on mortar rounds within an acceptable tolerance of 200 meters.

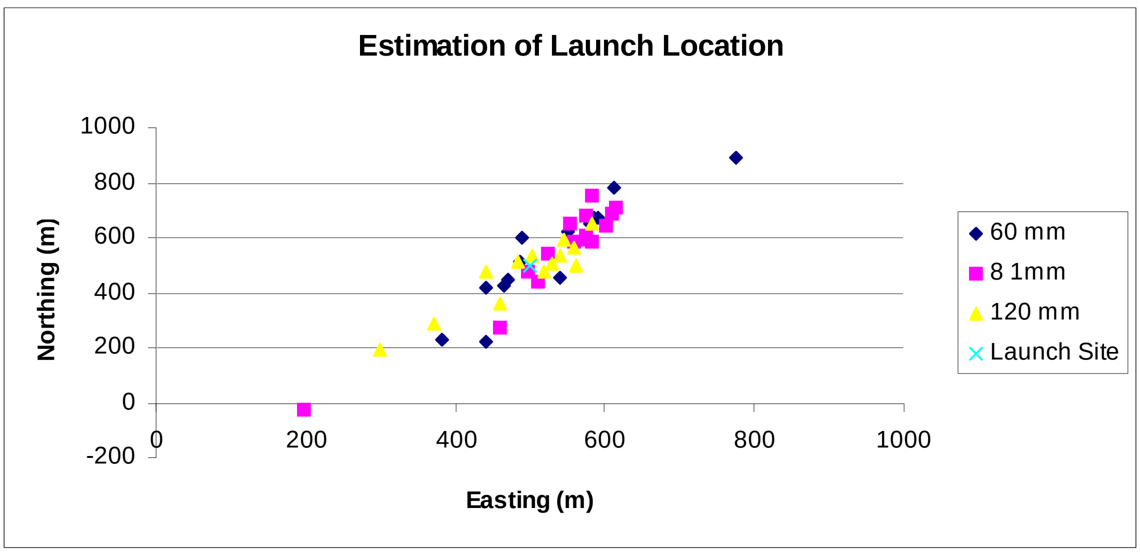

Figure 2. Estimation of launch location from gun position Hex11.1.

Figures 3 and 4 illustrate the algorithm's output as the gun position is varied. As expected, the accuracy of the results decreases as the distance between the gun position and the acoustic sensors increases. In figure 3, one will notice less detection for the 81-mm rounds than the other rounds; this was because of tube malfunction; 81-mm rounds were no longer used during this experiment.

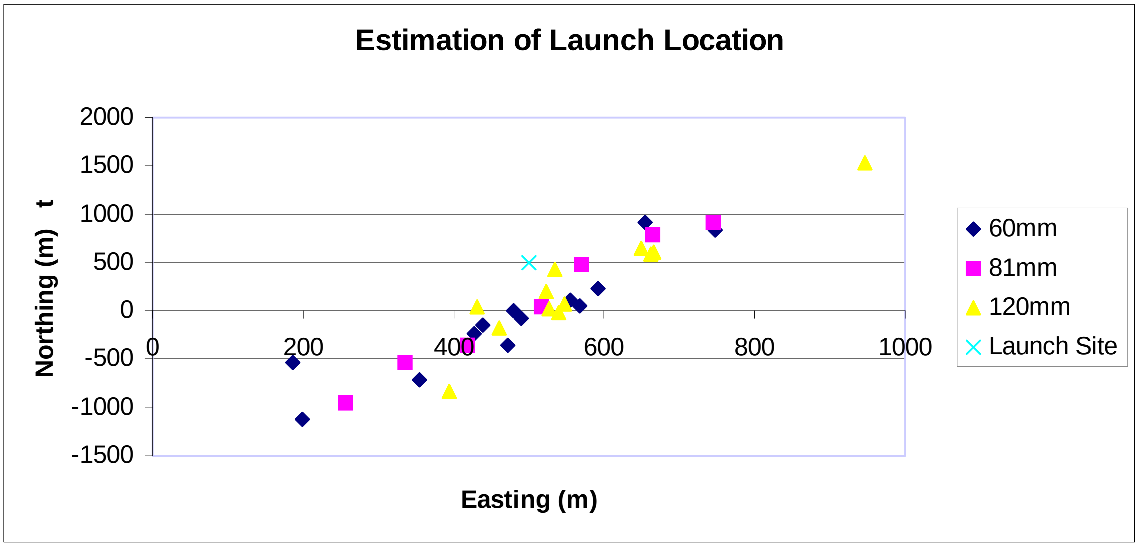

Figure 3. Estimation of launch location from gun position T8.9.

One will also notice two fewer 60-mm rounds in figure 4. This is believed to be a direct result of the tracker algorithm and its selection process. As mentioned before, the tracks are based on both angular distance and a windowed time frame. Therefore, if a legitimate track does not meet the specified requirements, it is rejected as noise.

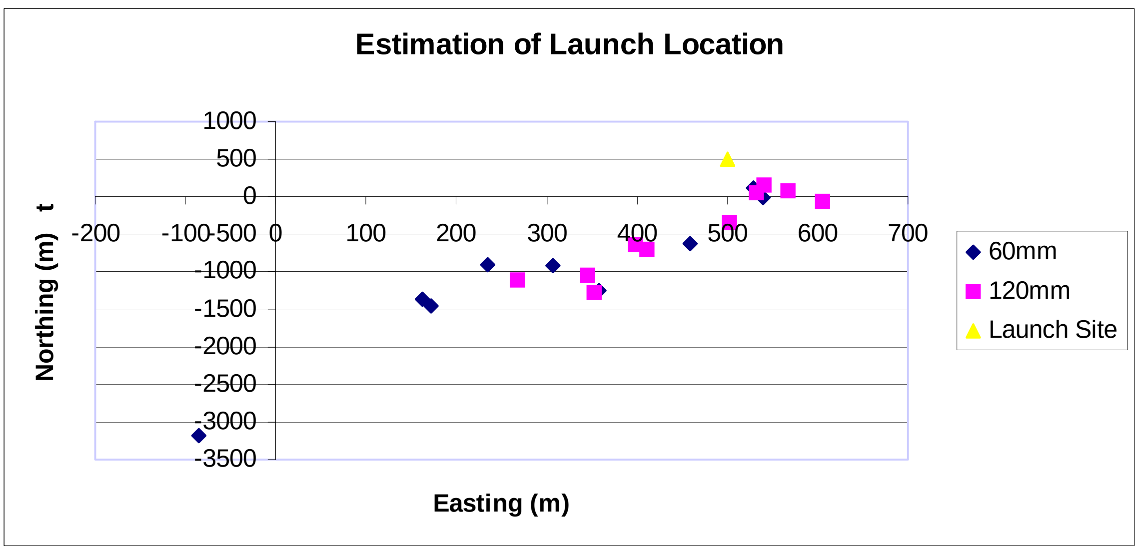

Figure 4. Estimation of launch location from gun position T6.8.

In figure 5 the algorithm was able to successfully localize on the propane cannon well within the acceptable tolerance. The propane cannon was not only closer to the acoustic sensors than the other gun positions, but it was also within the perimeter of the sensor configuration.

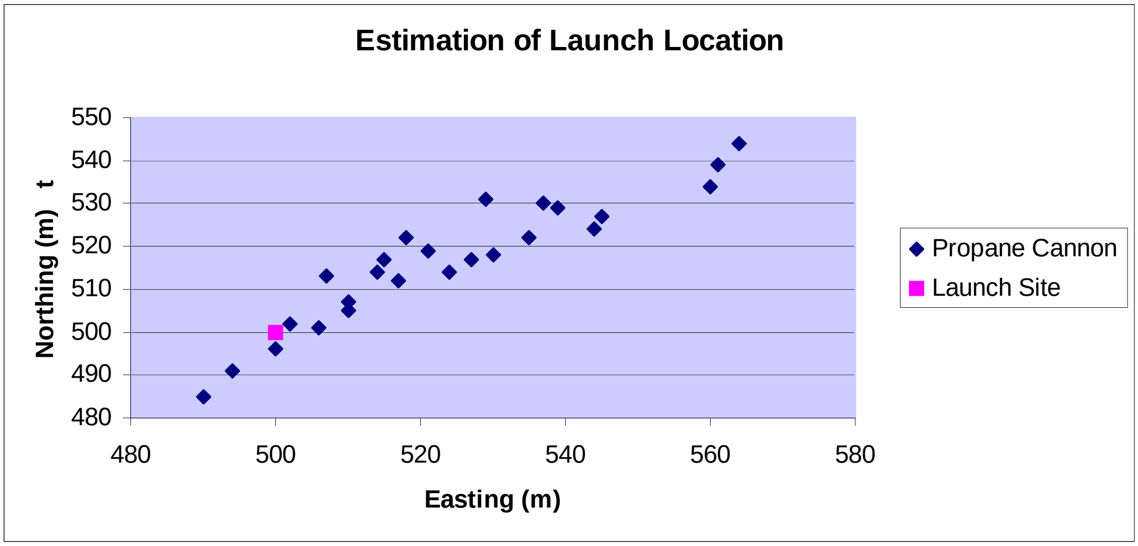

Figure 5. Estimation of launch location of propane cannon.

Table 1 contains the mean and axis error for each of the rounds as the gun location is changed. In general, the error increases the farther the gun position is away from the acoustic sensors. This is a direct effect of the distortion of sound as it travels through the atmosphere. There are also several other possible sources of error. The first and the most obvious is that the tracker occasionally rejected a correct solution for a less accurate one based on updated information. There have also been noticeable errors with the current global positioning system (GPS) on each sensor. If each GPS is off by a fraction of a meter, it can result in angular inaccuracies thus affecting the overall tracked solution. Acoustic sensors were also aligned with a magnetic compass. This is not ideal because metal, not obvious to the user, may pull the compass several degrees from the true value. Finally, this algorithm did not compensate for atmospheric and terrain conditions which become critical when one is analyzing data in extreme conditions.

Table 1. Mortar rounds along with their corresponding error as gun positions are varied.

Gun Position	Caliber	Mean Error (Easting)	Mean Error (Northing)	Minor Axis of Error Ellipse	Major Axis of Error Ellipse
Hex 11.1	60 mm	292.2	43.1	35.3	205.6
Hex 11.1	81 mm	70.6	120	19.0	107.5
Hex 11.1	120 mm	-29.5	-70.3	29.9	199.1
T 8.9	60 mm	-25.8	-580.5	59.7	558.6
T 8.9	81 mm	1.1429	-445.9	22.4	675.6
T 8.9	120 mm	73.3	-239.8	48.3	565.6
T 6.8	60 mm	-202.6	-1565.9	61.0	932.1
T6.8	120 mm	-47.8	-986.5	37.6	521.4
N/A	Propane Cannon	20.2	13.8	4.9	22.2

4. Conclusion

This report has demonstrated the capabilities of acoustic data to localize on mortars and other similar acoustic events within a certain tolerance. It has also highlighted some of the flaws associated with the acoustic localization, more specifically detection of outliers and multipath resembling that of acoustic threat. Our results indicate that this algorithm performs well when one is localizing on threats in reverberant environments; however, the use of a MAP estimator for noisy measurements may improve current accuracy. In addition to removing outlier and multipath noise, this estimator addresses the essential problem of association, where detections of the same event at different arrays have to be matched. Given the sequential nature of the measurements, a set of locations can be computed iteratively while an exhaustive combinatorial search is avoided. Finally, this research highlighted possible sources of error not directly associated with the tracker algorithm. These errors include GPS inaccuracy, the use of a magnetic compass for alignment purposes, and failure to incorporate MET and terrain conditions when ideal sensor location and track analysis are being determined. Properly accounting for the last three sources of error in future field experiments will further improve the accuracy of identifying threats of interest.

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