Shooter Localization

Sensor Fusion

Fredrik Gustafsson
fredrik.gustafsson@liu.se

Gustaf Hendeby
gustaf.hendeby@liu.se

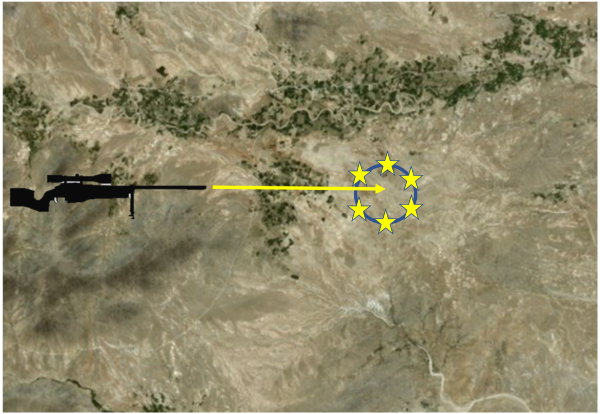
Linköping University

Purpose

Provide a challenging application on localization in sensor networks.

Background:

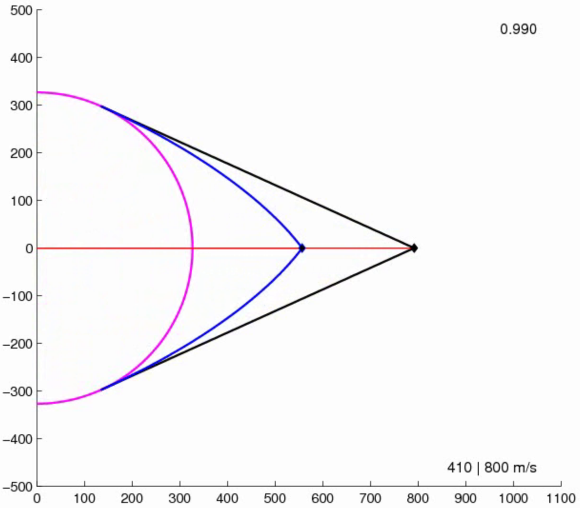
- Goal: Protect a UN camp to snipers.
- Estimation problem: find shooter location and aiming direction.
- Sensor network: Microphones placed around the camp.



Muzzle Blast and Shockwave

A supersonic bullet gives rise to both a shockwave from the bullet (compare to a bow wave from a boat) and a muzzle blast (explosive sound from the gun)

- Red: Bullet trajectory
- Black: Ideal shock wave
- Blue: Shock wave considering bullet retardation
- Magenta: Muzzle blast



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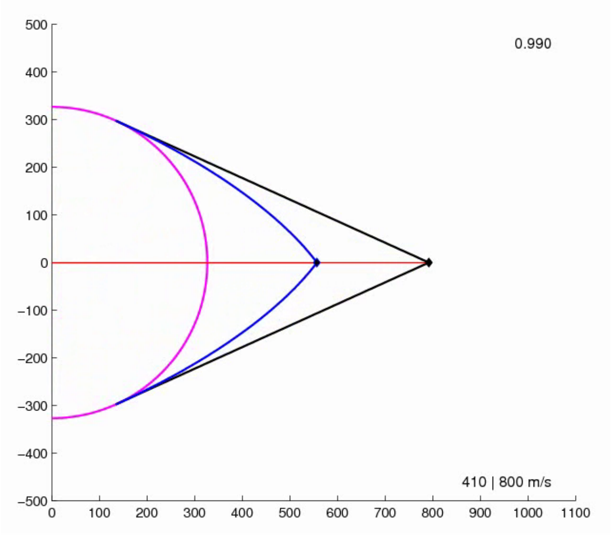

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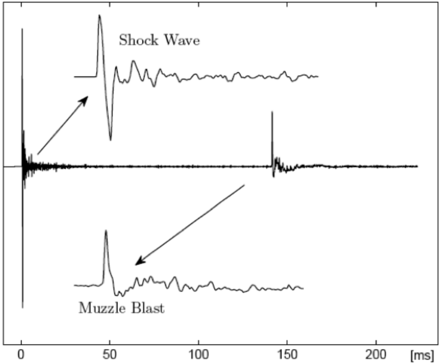
Sound Detection

- Shockwave comes first for a supersonic bullet
- Triangular waveform caused by the bullet, can be detected as a spike by a high-frequency microphone.
- The muzzle blast has a strong transient, followed by echoes and reverbation effects. The onset time of the transient can be detected from the microphone.



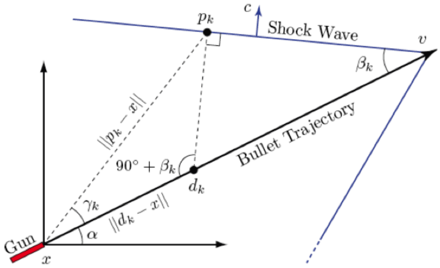
Sensor Model

Parameter vector

- Position X, Y of the shooter.
- Aiming angle α.
- Bullet initial speed v_0 and retardation factor r.
- Shooting time t_0 and sensor clock bias b_k.

Geometry gives the following sensor models:

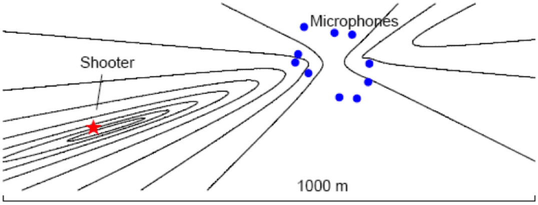
$$y_k^{mb} = t_0 + b_k + \frac{1}{c}\|p_k - x\| + e_k^{mb},$$
$$y_k^{sw} = t_0 + b_k + \frac{1}{r}\log\frac{v_0}{v_0 - r\|d_k - x\|} + \frac{1}{c}\|d_k - p_k\| + e_k^{sw}.$$



where d_k is an implicit function of the parameters x. The shooting time and clock bias are eliminated by taking the difference $y_k^{mb} - y_k^{sw}$ as the measurement!

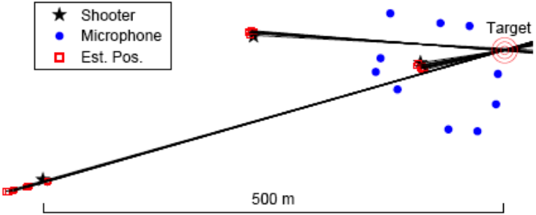
NLS Loss Function

- Field trials with multiple shots from multiple positions.
- Sensor network with ten microphones.
- NLS loss function illustrates the information in $y_k^{mb} - y_k^{sw}$, $k = 1, 2, \ldots, N = 10$.



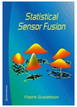
Estimation Results

- the figure summarizes estimates from multiple shots at multiple positions, every shot is aimed for the same target.
- Both shooter position and aiming direction α are well estimated for each shot.
- In particular, the estimated bullet trajectory passes very close to the target the shooter is aiming for.
- Also bullet's muzzle speed is estimated in the parameters. The ammunition length can be estimated from the sound detection algorithm. From this, important information about the weapon can be deduced.



Summary

- Microphone network to estimate position, aiming angle, bullet speed and bullet retardation.
- Signal processing to detect time of arrival of shock wave and muzzle blast.
- Time difference of arrival (TDOA) can with basic geometry be expressed as a function of the parameters.
- NLS based on multiple TDOA measurements gives an estimate of the parameters.
- Field tests resulted in very accurate estimates.
- Collaboration between FOI and LiU.



Section 16.1