University Defence Research Centre (UDRC)

In Signal Processing

Sponsored by the UK MOD

Passive Acoustic Sniper Localisation
(Joint Blind Enhancement and Passive Source Localisation of Acoustic Signals)

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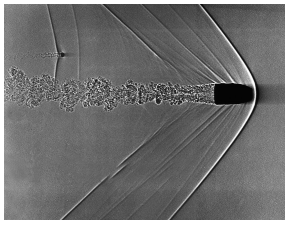
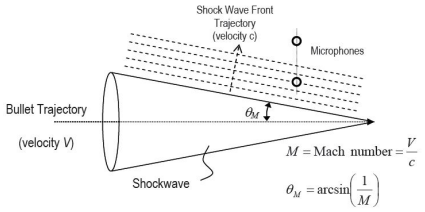
Objective: Main project objectives are to:

- Provide a unified joint tracking and enhancement (JTE) algorithm using statistical models that exploit both spatial diversity and target-source statistics.
- Investigate the detection and localisation of acoustic weapons fire in outdoor in-air acoustic environments; e.g. sniper localisation.
  1. Investigate channel models for outdoor in-air acoustic environments;
  2. Develop target-source models for non-speech signals such as gun-shots (for weapons localisation);

I. Overview of Technical Approach

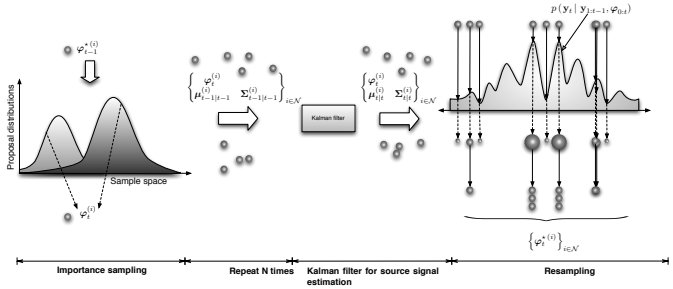


Shockwave from Supersonic Bullet Mach 1.5



Shockwave generation [Maher, 2008]

- Assume muzzle blast is not detectable, either through use of silencer, or severe attenuation. **Microphones detect shockwave front only.**
- Given assumed bullet trajectory, calibre, and N-wave model parameters, **predict** the signals received at microphones.
- **Compare** predictions with actual observations.
- **Update** estimated bullet parameters above using Rao-Blackwellised particle filter. Incorporate particle-filter based detection algorithm.

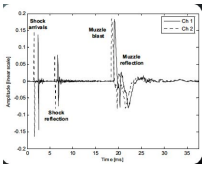


Rao-Blackwellised particle filter

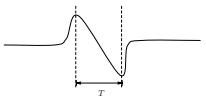
II. Progress to date

- Analysed bullet trajectory and shockwave geometry.
- Statistical signal modelling of N-wave (shockwave).
- State-space formulation of observed signal as function of bullet trajectory and N-wave parameters.
- Development of particle filter tracker for estimating bullet trajectory (assuming no reverberation).
- Development of shockwave detection algorithm within particle filter framework (initial tests on simulated data).
- **Available data**: Acoustic weapons firing events from NATO experiment.

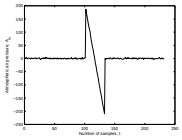
III. Shockwave model



Measured shockwave response.



Simplified N-wave model



Simulation: $d = 7.27m$, $\phi = 5.59mm$, $v = 685m/s$, SNR of $-5dB$, $f_s = 192kHz$.

- N-wave model (Whitman model):

$$x(t) = \begin{cases} A\left(1 - \frac{2}{Lm}\left(t - \tilde{\tau}\right)\right), & \tilde{\tau} \le t \le \tilde{\tau} + L \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

atmospheric peak amplitude $$A = \frac{0.53\, P_0\, (M^2 - 1)^{1/8}\, \phi}{d^{3/4}\, \ell^{1/4}} \quad \text{Pascals} \quad (2)$$

shockwave duration $$L = \frac{1.82\, M\, d^{1/4}\, \phi}{c(M^2 - 1)^{3/8}\, \ell^{1/4}} \quad \text{Seconds} \quad (3)$$

where d is the distance to the sensors, P_0 is atmospheric air pressure, M is the Mach number, ℓ the length of the bullet, ϕ its diameter.

- Received signal distorted by measurement noise:

$$\mathbf{y}_t = \mathbf{x}_t + \Sigma w_t\, \mathbf{w}_t, \qquad w_t \sim \mathcal{N}\left(\mathbf{0}_{M\times 1},\, \mathbf{I}_M\right) \quad (4)$$

where $\mathbf{y}_t$ are the measured observations at the sensors, $\mathbf{x}_t$ is the perfect N-wave predictions, , and $\Sigma w_t\, \Sigma w_t{}^T$ is the measurement noise covariance.

IV. Signal detection

- Assume signal is buried in background noise, receiver observes either
  1. the noise signals in the absence of a gunshot,
  2. or the ballistic N-wave signal when a shot is fired.
- Detection scheme implemented in PF framework by means of likelihood ratios.

for time index $t > 0$ **do**
  for sensor $m \in \mathcal{M}$ **do**
    for particle $i \in \mathcal{N}$ **do**
      Importance sampling of model parameters.
      Evaluation of importance weights from their likelihood function.
    end for
    Likelihood-ratio shockwave detection.
    Normalisation of weights.
    Resampling.
  end for
end for

Conclusion: Concluding remarks

1. Detection and localisation algorithm development near completion.
2. Test on relevant data sampled at sufficient sampling rate.

Perspectives:

1. **Competing work**: a related but different approach developed by Tampere University of Technology, Finland. A comparison needed.
2. **Related problems**: joint detection and tracking (Challenge 14). Also covers detection, high-resolution localisation, and multi-path mitigation.

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