University Defence Research Collaboration (UDRC)
Signal Processing in a Networked Battlespace

L_WP2: Handling uncertainty and incorporating domain knowledge (Loughborough University)

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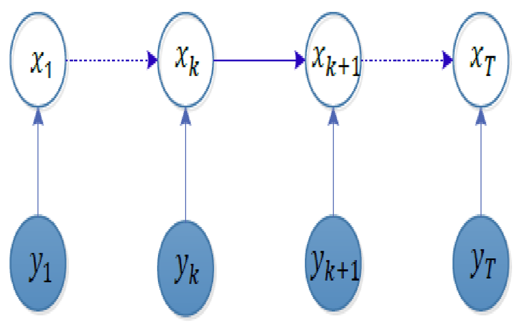
L_WP2.1 Reducing uncertainty by incorporating domain knowledge using Bayesian inference and adaptive signal processing

Objectives

- A framework to explore all the previously collected information and data available for moving platforms in a networked environment when performing signal process will be developed.
- New signal processing algorithms offering adaptivity to operational environments will be developed by exploiting domain knowledge.
- Extension will be made to multiple sensor platforms operating in a networked environment by fusing different types of information.

General Tracking Problem

Aim: Obtaining a Minimum Mean Square Error estimator (MMSE) and its confidence



State model: $x_k = f(x_{k-1}, v_k) \sim p(x_k|x_{k-1})$

Measurement model: $y_k = h(x_h, e_k) \sim p(y_k|x_k)$

x_k: state variable representing the state (position, velocity) of a vehicle

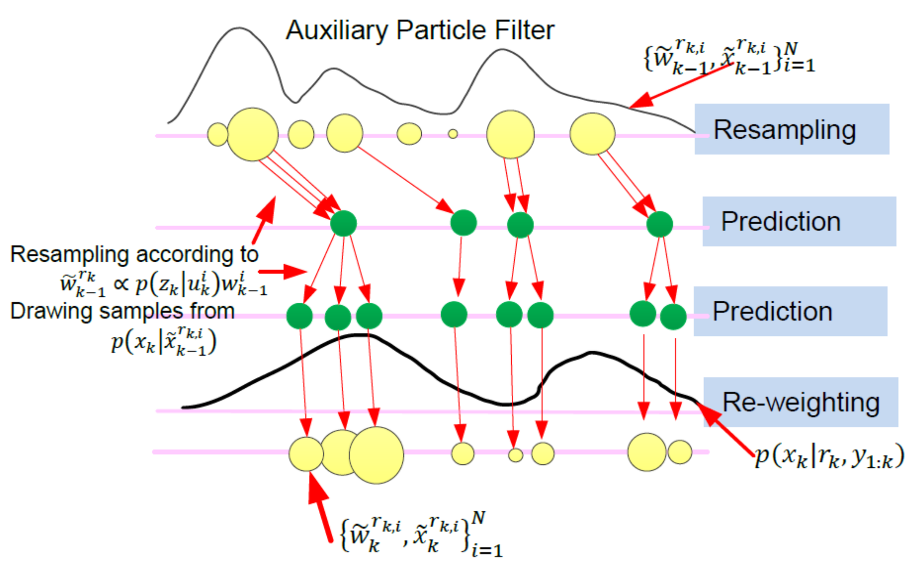
y_k: observation from different types of sensors

Bayesian Inference Scheme

Estimate both the posterior mode probability $p(r_k|y_{1:k})$ and the MMSE $E(x_k|r_k, y_{1:k})$ based on $p(x_k|r_k, y_{1:k})$, where r_k represents the mode.

It divides into three steps:

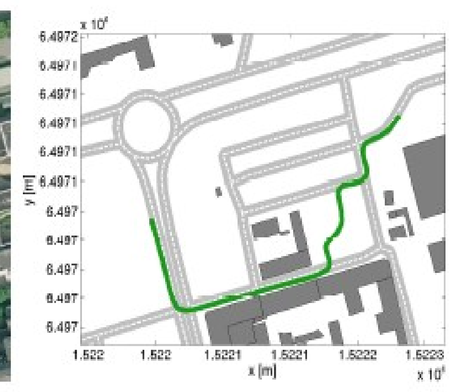
- Estimating the initial mode conditioned probability $p(x_{k-1}|r_k, y_{1:k-1})$
- Estimating $p(x_k|r_k, y_{1:k})$ using a filtering particle scheme such as an auxiliary particle filter
- Calculating the posterior mode probability $p(r_k|y_{1:k})$



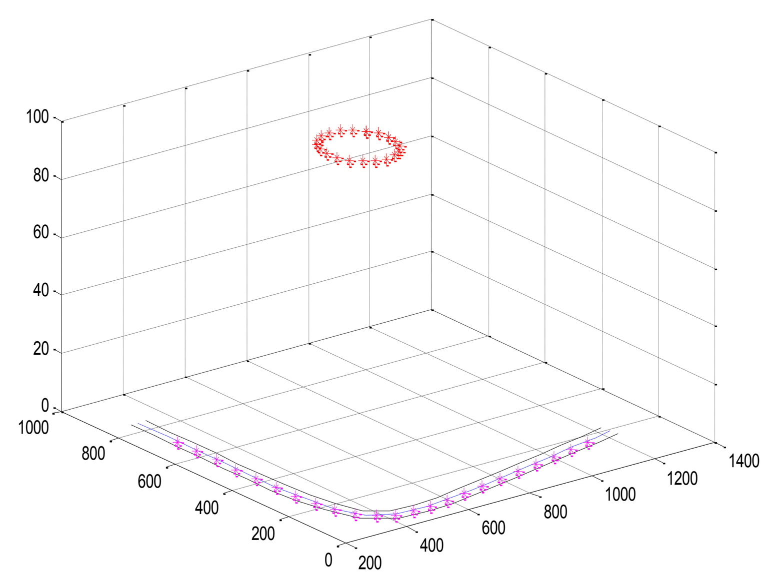
Auxiliary Particle Filter Scheme

Domain Knowledge

- Road geometry information: the movement of the vehicle is constrained by the shape of the road.
- Expert knowledge information: the movement of the vehicle is constrained by the properties of a road segment.



Simulated Scenario



- A UAV is simulated to circle around for monitoring the corresponding area.
- A vehicle moves on the ground with different types of manoeuvre.
- Bayesian inference scheme is applied and domain knowledge is incorporated to improve the performance.

Future Works

- *Scenarios*: More complicated scenarios like a vehicle moving both on and off road in battlefield, and urban environment will be studied.
- *Algorithms:* More advanced algorithms to enhance both the accuracy and efficiency (e.g. particle swarm optimization (PSO) based particle filtering method) will be investigated.
- *Knowledge*: More types of domain knowledge, such as the available information from the GIS system, will be applied.

L_WP2.2: Game Theoretic Framework for Radar Waveform Design

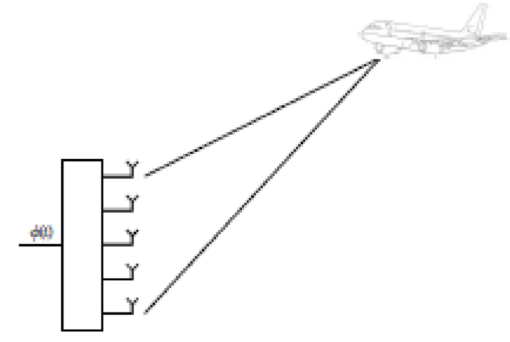
Objectives

- Understand uncertainties caused deliberately by intelligent targets equipped with jammers, and develop game theoretic methods for radar waveform design that is robust against jamming.
- Enhance the defence against jamming within a radar network environment through the distributed resource allocation and waveform design, with a focus on MIMO radars.

MIMO Radars

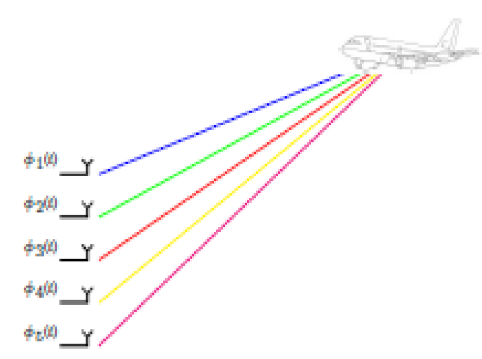
Phased Arrays:

- Coherent beam
- High antenna gain (good SNR)
- Good detection performance in low SNR



MIMO (Multiple-Input-Multiple-Output) Radar:

- Transmission of independent signals (waveform diversity)
- Detection of slow moving targets
- Improved parameter identifiability



Game Theory

Game theory provides the means to model, analyse and understand situations involving interactions among various decision-makers.

- A game G is a tuple $< N, (A_i), (u_i) >$, where
  - N is a set of players
  - A_i is a set of actions associated with each player i
  - u_i is a payoff function, which represents the players' preferences on the actions
- The solution of a game is a systematic description of the outcomes that may emerge in a family of games.


John Forbes Nash, Jr.

Nash equilibrium is the action profile such that no player can profitably deviate from their strategy.

Current Research Direction

Game theoretic framework for beamforming design for a radar network with power constraints, where the beamforming is considered in transmission and reception.

- The radars in the network aim to detect the same target.
- Each radar acts independently (non-cooperative game).
- Each radar should not deliberately interfere with the signal of the other radars.
- The radars have limited power.

Future Works

Case 1	Case 2
Players: network of phased-array	**Players**: network of MIMO radars vs intelligent target equipped with a jammer
Aim: achieve good detection performance while keeping interference at low levels	**Aim**: **Radar**: maximize detection performance **Target**: deliberate interference to minimize detection performance
Strategy: beamforming design, power allocation	**Strategy**: waveform design, power allocation
Payoff: SINR, probability of false alarm and miss-detection	**Payoff:** SINR, probability of false alarm and miss-detection

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