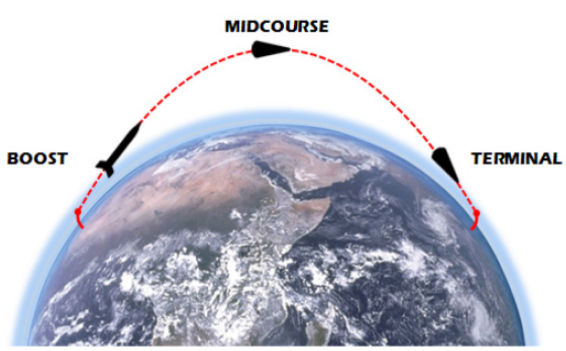
University Defence Research Collaboration in Signal Processing

LSSC Consortium White Paper

Reducing Uncertainty by Incorporating Domain Knowledge Using a Bayesian Framework

Introduction

Due to the abundance of information collected on the battlefield and increasing communication and storage capability, domain knowledge is immediately available to a sensor platform. This can be exploited to reduce uncertainty for signal processing. To incorporate such domain knowledge, we have applied a generic Bayesian framework. Domain knowledge is represented as probabilities and incorporated within the prior distribution construction. Sensor measurements are collected and converted to probabilities as measurement likelihoods to update the prior and obtain a refined posterior distribution.



PHASES OF BALLISTIC MISSILE FLIGHT

A specific application of ballistic missile tracking illustrates the idea of applying a generic Bayesian framework for domain knowledge incorporation. The ballistic missile is an example of a threat from the air in modern warfare. To intercept the ballistic missile, it first needs to be tracked to obtain its state (position, velocity, etc.).

Although different techniques have been applied for tracking a ballistic missile; they usually concentrate on tracking the ballistic missile during a particular flight phase. Some works have attempted to track the whole flight trajectory, using an interactive multiple model (IMM) based method as in [1]. However, in that work, there is an unrealistic constant transition probability assumption for the traditional IMM. Moreover, the extended Kalman filtering applied in the IMM scheme is limited in dealing with the highly non-linear models inherent in the BM scenario.

Method

A Bayesian framework is exploited to incorporate domain knowledge to achieve more accurate ballistic missile tracking over the whole flight trajectory. Under the framework, different state models are applied considering different movement characteristics of a ballistic missile within different phases. The domain knowledge, for example--the ballistic missile cannot transit from the boost to midcourse when its altitude is low, is used to construct more realistic model transition probabilities and reduce the uncertainty in the model determination. Different types of sensors, such as radar, could be applied to measure ballistic missile parameters.

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Considering the non-linearity of the state and measurement models and non-Gaussian properties due to the incorporation of multiple models, a particle filtering based approach, called the state dependent interactive multiple model particle filter (SD-IMMPF) [2] is applied to implement the Bayesian framework for the ballistic missile state estimation. Compared with the traditional IMM method as in [1]:

- more realistic model transition probabilities are considered, and
- a particle filtering approach is applied to overcome the highly non-linear state and measurement models

The developed IMMPF algorithm has been compared with the traditional IMM method for tracking the ballistic missile trajectory. A simulation of the whole trajectory is made according to parameters in [3] and the root-mean-square-errors (RMSEs) from multiple Monte-Carlo simulations at every time instance are calculated.

Smaller tracking errors are obtained by the proposed method, especially around time instances when the flight phase transitions occur.

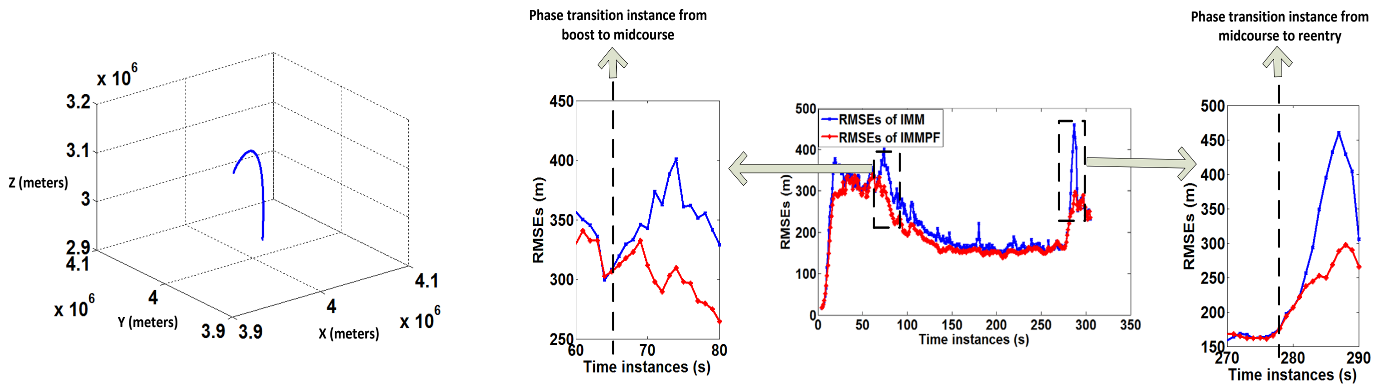

Figure 1: Simulated trajectory and Monte-Carlo analysis for position errors.

The proposed Bayesian framework for domain knowledge incorporation and IMMPF implementation algorithms could be extended to other applications, such as ground vehicle tracking, aircraft tracking, object localization, etc.

References:

[1]. Missiles&Other WMD Delivery Systems, http://tutorials.nti.org/delivery-system/understanding-missiles/, accessed in November, 2015.

[2] W. Farrell, “Interacting Multiple Model Filter for Tactical Ballistic Missile Tracking”, IEEE Transactions on Aerospace and Electronic Systems, Vol. 44, No. 2, Pages 418—426, 2008.

[3] C. Liu, B. Li and W.-H. Chen. Road network based vehicle navigation using an improved IMM particle filter. Proceeding of IFAC Intelligent Autonomous Vehicles Symposium 2013, 2013.

[4] Defence against airborne threats competition document, https://www.gov.uk/government/publications/cde-themed-competition-defence-against-airborne-threats, accessed in August, 2015.