Title:

Bayesian Networks for Interpretable and Extensible Multi-Sensor Fusion

Abstract:

In response to the broad range of threats experienced across the battlespace, modern defense systems have trended toward high levels of interconnectedness on the assumption that information from systems spanning numerous domains will be fused at the speed of relevance. One regime emblematic of these types of challenges is that of modern air defense, in which threats are increasing in sophistication and numerosity. To ensure the success of next generation defense systems, we need solutions where legacy and next generation sensors coexist and cohesively integrate information across domains and sources. Neural network-based approaches have demonstrated significant capabilities in dealing with complex data processing and fusion systems, however, in the context of safety critical defense systems there are various limitations that hinder their deployment. In particular, the lack of explainable outputs, the need for large amounts of data, which is typically lacking or severely limited in defense settings, and their high computational costs make NN-based solutions unsuitable. Often overlooked are more traditional and intuitive machine learning techniques such as Bayesian networks.

The attributes of Bayesian networks such flexibility, ease of use, lightweight computational needs, and innate explainability and reasoning capabilities has already led to their successful application in air defense, for target tracking, identification, and intent classification. These same attributes also make Bayesian networks suitable for use in high level multi-sensor fusion. In this work we showcase the feasibility of using Bayesian networks as an extensible and dynamic multi-sensor fusion system to perform reasoning over any number of disparate black-box approaches, as well as their utility in producing more reliable, trustable, and interpretable results than any individual sensor system operating independently. We also demonstrate the ability of Bayesian networks to produce compelling results without incurring the computational overhead and difficulties associated with interpreting the results of large neural network-based approaches.

Abstract Structure:

1. General Context, Domain Context, Specific Context
2. Motivation (cohesive integration)
3. Shortcomings of Historical/Alternate Approaches
4. Primary Technical Topic: Bayesian Networks
5. Historical usage of Bayesian Networks, and advantages (addressing Shortcomings)
6. Research and Analytical Methods
7. Results:
   1. Reliable, Trustable, Interpretable
   2. Compelling results without overhead or difficulties

Original Paper Section Headers

1. Introduction
2. Background and Related Work
3. Proposed Bayesian Network
   1. Features and Network Design
   2. Conditional Probability Distributions
4. Example Test Cases
   1. Network Calibration – No Observations
   2. Test Case 1 – Missile in Cruise
   3. Test Case 2 – Bomber in Attack
   4. Test Case 3 – Bomber with Stealth under Inclement
   5. Test Case 4 – Camera and Radar Offline
   6. Test Case 5 – Externally Resolved Object
5. Conclusions

Combining Original Sections with Abstract Sections:

1. Introduction
   1. General Context, Domain Context, Specific Context
   2. Motivation (cohesive integration)
2. Background and Related Work
   1. Shortcomings of Historical/Alternate Approaches
   2. Primary Technical Topic: Bayesian Networks
   3. Historical usage of Bayesian Networks, and advantages (addressing Shortcomings)
3. Proposed Bayesian Network (Research Methods)
   1. Features and Network Design
   2. Conditional Probability Distributions
4. Example Test Cases (Analytical Methods)
   1. Network Calibration – No Observations
   2. Test Case 1 – Missile in Cruise
      1. Reliable, Trustable, Interpretable
      2. Compelling results without overhead or difficulties
   3. Test Case 2 – Bomber in Attack
      1. “”
   4. Test Case 3 – Bomber with Stealth under Inclement
      1. “”
   5. Test Case 4 – Camera and Radar Offline
      1. “”
   6. Test Case 5 – Externally Resolved Object
      1. “”
5. Conclusions
   1. Reiterate advantages of Bayesian Networks