20th IAA SYMPOSIUM ON SPACE DEBRIS (A6)
Operations in Space Debris Environment, Situational Awareness - SSA (7)

Author: Dr. Han Cai
Beijing Institute of Technology, China, caihanspace@gmail.com

Ms. Yifan Cai
Beijing Institute of Technology, China, caiyifan@bit.edu.cn
Prof. Jingrui Zhang
Beijing Institude of technology, China, zhangjingrui@bit.edu.cn
Dr. Sifeng Bi
University of Strathclyde / Mechanical and Aerospace Engineering, United Kingdom,
sifeng.bi@strath.ac.uk

# MULTIPLE SPACE OBJECT TRACKING UNDER EPISTEMIC UNCERTAINTY

**Abstract**

Multiple space object tracking is a challenging task. The state, number, and trajectory of space objects vary frequently due to the complexity of space environment. Multi-target tracking filtering methods have been intensively studied by the Space Situational Awareness (SSA) community to address these issues. An essential requirement in typical methods is to model various sources of uncertainty as random variables that follow some probability distributions. However, the probabilistic representation may be ill-adapted to some uncertain components that result from the absence of knowledge. This type of uncertainty that comes from ignorance is referred to as epistemic uncertainty. Representing epistemic uncertainty based on probability theory can produce potentially catastrophic operational implications in SSA, e.g., the probability dilution effect in conjunction assessment.

An appealing alternative for uncertainty representation is the Outer Probability Measure (OPM). OPM provides a faithful representation of epistemic uncertainty, which accounts for the limited or imperfect information one possesses of the system. Closed-form stochastic filtering solutions based on OPMs, dubbed possibility filter, have been derived for a recursive uninformative prior Bayesian estimation. The possibility Bernoulli filter has been developed as a more robust estimation algorithm for single-target tracking in the presence of epistemic uncertainty.

Motivated by previous research, this paper presents a flexible modeling framework for multi-target tracking based on OPMs. The notion of labeled uncertain finite set is introduced and utilized as the basis to derive a possibilistic analog of the $\delta$-Generalized Labeled Multi-Bernoulli ($\delta$-GLMB) filter, in which the uncertainty in the multi-target system is represented by possibility functions instead of probability distributions. The proposed method inherits the capability of the standard probabilistic $\delta$-GLMB filter to yield joint state, number, and trajectory estimates of multiple appearing and disappearing targets. Beyond that, it is capable to account for epistemic uncertainty due to ignorance or partial knowledge regarding the multi-target system, e.g., the absence of complete information on dynamical model parameters (e.g., detection probability, existence probability) and initial number and state of newborn targets.

The features of the developed filter are demonstrated using two simulated GEO space object tracking scenarios by comparing with the probabilistic $\delta$-GLMB filter. In the first case, we study the performance of the filter in the absence of exact knowledge on detection probability. In the second case, a more challenging case is designed to validate the robustness of the proposed method in the situation of limit information about newborn targets.