Tutorial: Poisson multi-Bernoulli mixtures for multiple target tracking

Length of the tutorial: 3-hour.

Intended audience and prerequisites: The intended audience are researchers with previous knowledge in single target tracking and Kalman filtering, for example, PhD students, researchers working in the industry and academics. Basic understanding of random finite sets will also be helpful.

Presenter: Yuxuan Xia.

Material prepared in collaboration with: Ángel F. García-Fernández, Lennart Svensson, Karl Granström.

Description:

In this tutorial, the attendant will learn the foundations of the Poisson multi-Bernoulli mixture (PMBM) filter, a state-of-the-art multiple target tracking (MTT) algorithm [1][2] that has been applied to data from lidars, radars, cameras, integrated search-and-track sensor management [3], 5-G simultaneous localization and mapping [4]. In addition, the attendant will learn the relations of the PMBM filter with other MTT algorithms such as multi-Bernoulli mixture (MBM) filter [2], probability hypothesis density (PHD) filter [5], Poisson multi-Bernoulli (PMB) filter [1], δ-generalised labelled multi-Bernoulli (δ-GLMB) filter [6], multiple hypothesis tracking (MHT) [7], and joint integrated probabilistic data association (JIPDA) filter [8]. Finally, this tutorial will cover the extension of the PMBM filter to sets of trajectories to include full trajectory information [9].

The outline and learning objectives of the tutorial will be:

- Basic notions of random finite sets: multi-target density, cardinality distribution, PHD, convolution formula.
- Basic types of random finite sets: Poisson, Bernoulli, multi-Bernoulli.
- PMBM filtering: overview of its structure, prediction and update.
- The MBM filter: a special case of PMBM filtering.
- Relation between PMBM/MBM filters and the δ -GLMB filter, including adaptive birth.
- Relation to approximate filters: PMB and PHD filters.
- PMB filters obtained via belief propagation.
- Relation to classic MTT approaches: MHT, and JIPDA.
- Extension of the PMBM filter to sets of trajectories to obtain full trajectory information.

Implementations of the most relevant algorithms and slides will also be provided. This tutorial is complemented by the edX/YouTube course on multiple object tracking in [10][11], where comprehensive material and exercises are provided.

References

[1] J. L. Williams, "Marginal multi-Bernoulli filters: RFS derivation of MHT, JIPDA, and association-based member," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 51, no. 3, pp. 1664-1687, July 2015.

[2] Á. F. García-Fernández, J. L. Williams, K. Granström and L. Svensson, "Poisson Multi-Bernoulli Mixture Filter: Direct Derivation and Implementation," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 54, no. 4, pp. 1883-1901, Aug. 2018.

[3] P. Bostrom-Rost, D. Axehill and G. Hendeby, "Sensor management for search and track using the Poisson multi-Bernoulli mixture filter," in *IEEE Transactions on Aerospace and Electronic Systems*.

[4] Y. Ge *et al*., "A Computationally Efficient EK-PMBM Filter for Bistatic mmWave Radio SLAM," in *IEEE Journal on Selected Areas in Communications*.

[5] R. P. S. Mahler, Advances in Statistical Multisource-Multitarget Information Fusion. Artech House, 2014.

[6] B. T. Vo and B. N. Vo, “Labeled random finite sets and multi-object conjugate priors,” *IEEE Transactions on Signal Processing*, vol. 61, no. 13, pp. 3460–3475, July 2013.

[7] E. Brekke and M. Chitre, "Relationship Between Finite Set Statistics and the Multiple Hypothesis Tracker," in *IEEE Trans. on Aerospace and Electronic Syst*, vol. 54, no. 4, pp. 1902-1917, Aug. 2018.

[8] D. Musicki and R. Evans, "Joint integrated probabilistic data association: JIPDA," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 40, no. 3, pp. 1093-1099, July 2004.

[9] Á. F. García-Fernández, L. Svensson and M. R. Morelande, "Multiple Target Tracking Based on Sets of Trajectories," in *IEEE Transactions on Aerospace and Electronic Systems*.

[10] https://www.edx.org/course/multi-object-tracking-for-automotive-systems

[11] https://www.youtube.com/channel/UCa2-fpj6AV8T6JK1uTRuFpw

Biographical sketches (All the presenters have experience in tutorial delivery)

Ángel F. García-Fernández received the telecommunication engineering degree and the Ph.D. degree from Universidad Politécnica de Madrid, Madrid, Spain, in 2007 and 2011, respectively. He is currently a Senior Lecturer in the Department of Electrical Engineering and Electronics at the University of Liverpool, Liverpool, U.K. His main research activities and interests are in the area of Bayesian inference, with emphasis on nonlinear dynamic systems and multiple target tracking. He has received 3 paper awards at the International Conference on Information Fusion.

Yuxuan Xia received the M.Sc. degree in communication engineering and the Ph.D. degree in signals and systems from Chalmers University of Technology, Gothenburg, Sweden, in 2017 and 2022, respectively. After obtaining his Ph.D. degree, he stayed at the Signal Processing group, the Department of Electrical Engineering as a postdoctoral researcher for a year. He is currently an industrial postdoctoral researcher at Zenseact AB, Gothenburg, Sweden and affiliated with the Division of Automatic Control, Linköping University, Linköping, Sweden. His main research interests include sensor fusion, multi-object tracking and SLAM, especially for automotive applications.

Lennart Svensson received the M.S. degree in electrical engineering in 1999 and the Ph.D. degree in 2004, both from Chalmers University of Technology, Gothenburg, Sweden. He is currently a Professor of Signal Processing with the Chalmers University of Technology. His main research interests include machine learning and Bayesian inference in general, and nonlinear filtering, deep learning, and tracking in particular. He has organized a massive open online course on multiple object tracking, available on edX and YouTube, and received paper awards at the International Conference on Information Fusion in 2009, 2010, 2017, 2019 and 2021.

Karl Granström is a perception specialist at Zoox, USA. He received the MSc degree in Applied Physics and Electrical Engineering in May 2008, and the PhD degree in Automatic Control in November 2012, both from Linkoping University, Sweden. His research interests include estimation theory, multiple model estimation, sensor fusion and target tracking, especially for extended targets. He has received paper awards at the Fusion 2011 and Fusion 2012 conferences. In 2018 the International Society of Information Fusion (ISIF) awarded him the ISIF Young Investigator Award for his contributions to extended object tracking and his service to the research community.