Extended and Group Object Tracking: Theory and Applications *FUSION 2017 Full-day Tutorial Proposal*

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***Abstract*—Autonomous systems are an active area of research and technological development. These systems require intelligence and decision making, including intelligent sensing, data collection and processing, collision avoidance and control. Autonomous systems, especially autonomous cars need to be able to detect, recognise, classify and track objects of interest, including their location and size. In the light of autonomous systems his tutorial will focus on tracking of extended objects and group objects, i.e., object tracking using modern high resolution sensors that give multiple detections per object. State of the art theory will be introduced, and relevant real world applications will be shown where different object types, e.g., pedestrians, bicyclists, and cars, are tracked using different sensors such as lidar, radar, and camera.**

I. AIM AND SCOPE

The multiple object tracking problem is defined as keeping track of an unknown number of moving objects, and historically it has been focused on so called point objects which give at most one detection per time step. However, modern sensors have increasingly higher resolution, meaning that it is common to see multiple detections per object. For example, this is the case when automotive radar or lidar sensors are used. In order to be able to use point object algorithms for these sensors, heuristic clustering algorithms are applied to the raw measurements to obtain object hypotheses. In challenging scenarios, the hard decisions of the clustering algorithms affect the performance of the tracking algorithm due to the associated loss of information. Consequently, so called extended object tracking algorithms which are capable of handling several measurements per object are required.

With multiple detections it also becomes possible to estimate the objects' shapes and sizes, in addition to the objects' locations and dynamical properties such as velocity and turn-rate. For an autonomous vehicle operating in a crowded urban area it is of high importance to be able to know if an object is a car, a bicyclist, a pedestrian, or belongs to some other category. The estimates of the shape and size are very important as they can be utilised in the process of distinguishing between different object types.

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Closely related to extended object tracking is so called group object tracking, where a group of objects are tracked together. Similarly to extended target tracking, a group object will cause multiple sensor detections, and it is of interest to estimate the shape and the size of the group.

The aim of this tutorial is to introduce the audience to extended and group object tracking, with a focus on both the underlying theory and relevant real world applications. The object tracking problem will be defined and several modern multi-object tracking algorithms for point objects will be introduced. As an example, the multi-sensor tracking system of the autonomous car at Ulm University is presented and the difficulties due to the usage of the point object assumption are illustrated. Afterwards, the modelling of object shapes and measurements in extended object tracking algorithms are introduced in detail and the integration in multi-object tracking algorithms is outlined. Finally, several applications of the presented extended object algorithms in automotive applications are shown.

II. TOPICS

The following topics will be included in the tutorial:

- Theory:
  - Brief review of state estimation: Kalman filter (KF), Extended KF (EKF), Unscented KF (UKF), particle filter (PF), Bayesian conjugate priors.
  - Shape parametrization: from simple geometric shapes to complex arbitrary shapes
  - Measurement modeling: number of detections per object and type of measurement spread. Poisson Point Process spatial model. Modelling based on reflection points located on a rigid body.
  - Multiple model approaches
  - Tracking multiple extended objects: Probability Hypothesis Density (PHD) filter, Cardinalized PHD filter, Labelled Multi-Bernoulli filters, Poisson Multi-Bernoulli filters.
  - Tracking multiple group objects using models of in-group interactions, such as social force models.
  - Sequential Monte Carlo approaches: Sampling Importance Resampling (SIR) PF, Box PF, Convolution PF, Gaussian Mixture SMC, and Markov Chain Monte Carlo (MCMC) methods.

- Applications:
  - Tracking of different object types: pedestrians, bicycles, and cars
  - Different sensor modalities: lidar, camera, and radar
  - Occlusion modeling in dense urban environments

III. Intended audience and prerequisite knowledge

The intended audience is academics and professionals with an interest in multiple extended object estimation. Recommended prerequisite knowledge is linear algebra, probability theory and state estimation. Knowledge of Random Finite Set (RFS) based algorithms for point target tracking is helpful, but not necessary.

IV. Course material

No specific material is required. Copies of the course slides will be provided to the attendees. Some Matlab code will be made available.

V. Length of tutorial

The preferred length of the tutorial is 6 hours.

VI. Organizers

The tutorial is organized by Karl Granström, Marcus Baum and Lyudmila Mihaylova. Together the authors many years of extended object tracking experience, they have published several well cited journal articles and conference papers on the topic, and the authors have received best paper awards at the annual Information Fusion Conference.

Biographical sketches, including previous lecture and tutorial experience, are given below.

A. Karl Granström

Karl Granström is a postdoctoral research fellow at the Department of Signals and Systems, Chalmers University of Technology, Gothenburg, Sweden. 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 Linköping University, Sweden. He previously held postdoctoral positions at the Department of Electrical and Computer Engineering at University of Connecticut, USA, from September 2014 to August 2015, and at the Department of Electrical Engineering of Linköping University from December 2012 to August 2014. 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.

Karl Granström has 10 years experience teaching courses on automatic control, signal processing and sensor fusion at Linköping University, and at Chalmers University of Technology. He has co-organized tutorials about multiplte target tracking, with a focus on extended targets, at the European Microwave Week (EuMW 2012), the IEEE Intelligent Vehicles Conference (IV 2017), the International Conference on Information Fusion (FUSION 2017), and the Multi-Sensor Fusion and Integration Conference (MFI 2017).

B. Marcus Baum

Marcus Baum is Juniorprofessor (Assistant Professor) at the University of Göttingen, Germany. He received the Diploma degree in computer science from the University of Karlsruhe (TH), Germany, in 2007, and graduated as Dr.-Ing. (Doctor of Engineering) at the Karlsruhe Institute of Technology (KIT), Germany, in 2013. From 2013 to 2014, he was postdoc and assistant research professor at the University of Connecticut, CT, USA. His research interests are in the field of data fusion, estimation, and tracking. Marcus Baum is associate administrative editor of the ”Journal of Advances in Information Fusion (JAIF)” and serves as local arrangement chair of the ”19th International Conference on Information Fusion (FUSION 2016)”. He received the best student paper award at the FUSION 2011 conference.

Marcus Baum has 8 years experience in teaching courses on sensor data fusion, localization and tracking at several universities. Currently, he is teaching a graduate course on ”Sensor Data Fusion” at the University of Göttingen.

C. Lyudmila Mihaylova

Professor Lyudmila Mihaylova and her team are working to develop novel methods for autonomous intelligent systems: for sensing, tracking and decision making, machine learning and their engineering applications. Prof. Mihaylova undertook pioneering work on traffic flow estimation with particle filtering for intelligent transportation systems which was followed later with developments for large scale systems, including large scale transportation and video processing systems. She has experience with a range of image modalities, including optical, thermal, LIDAR, SAR and hyperspectral image processing. Her interests are in the area of nonlinear filtering, sequential Monte Carlo Methods, statistical signal processing and sensor data fusion. Her work involves the development of novel techniques, e.g. for high dimensional problems (including vehicular traffic flow estimation and image processing) and localisation and positioning in sensor networks. Prof. Mihaylova is an Associate Editor of the IEEE Transactions on Aerospace and Electronic Systems, an Associate Editor of Elsevier Signal Processing . She is the President of the International Society of Information Fusion (ISIF) and an ISIF board member.