FUSION2020 TUTORIAL PROGRAM INFORMATION

Tutorials:

T1. Registration and Fusion of Multiple Sensors for the 3D Reconstruction of the Environment with Classical and Deep Learning Methods

Speaker(s): Nina Felicitas Heide (Fraunhofer)
Duration: 3 hours
Abstract: 3D reconstruction is crucial in many research areas ranging from perception for robots over monitoring of construction progress to person indoor navigation. My research at the Fraunhofer IOSB, Europe´s largest research institute in the field of image acquisition, processing and analysis, focuses on the 3D reconstruction of the environment, mainly with camera systems and LiDAR sensors. Here, proper registration of the data respectively calibration of the sensors providing it is the key to successful fusion of measurements from multiple sensors of the same or of different measurements principles. As registration is often edged out to focus on the more representative results from data fusion special attention is laid on this essential first step. The subsequent fusion of the sensor data as well as its real-world application in robotics and person indoor navigation is also presented in detail.

T2. Multitarget Tracking and Multisensor Information Fusion

Speaker(s): Yaakov Bar-Shalom (University of Connecticut)
Duration: 3 hours
Abstract: This tutorial will provide to the participants the latest state-of-the art techniques to estimate the states of multiple targets with multisensor information fusion. Tools for algorithm selection, design and evaluation will be presented. These form the basis of automated decision systems for advanced surveillance and targeting. The various information processing configurations for fusion are described, including the recently solved track-to-track fusion from heterogeneous sensors. The course is based on the book [1] Y. Bar-Shalom, P. K. Willett and X. Tian, Tracking and Data Fusion, YBS Publishing, 2011, and additional notes. Background text: [2] Y. Bar-Shalom, X. R. Li and T. Kirubarajan, Estimation with Applications to Tracking and Navigation: Algorithms and Software for Information Extraction, Wiley, 2001.

T4. Overview of High-Level Information Fusion Theory, Models, and Representations

Speaker(s): Erik Blasch (AFRL)
Duration: 3 hours
Abstract: Over the past decade, the ISIF community has put together special sessions, panel discussions, and concept papers to capture the methodologies, directions, needs, and grand challenges of high-level information fusion (HLIF) in practical system designs. This tutorial

brings together the contemporary concepts, models, and definitions to give the attendee a summary of the state-of-the-art in HLIF. Analogies from low-level information fusion (LLIF) of object tracking and identification are extended to the HLIF concepts of situation/impact assessment and process/user refinement. HLIF theories (operational, functional, formal, cognitive) are mapped to representations (semantics, ontologies, axiomatics, and agents) with contemporary issues of modelling, testbeds, evaluation, and human-machine interfaces. Discussions with examples of search and rescue, cyber analysis, and battlefield awareness are presented. The attendee will gain an appreciation of HLIF through the topic organization from the perspectives of numerous authors, practitioners, and developers of information fusion systems. The tutorial is organized as per the recent text: E. P. Blasch, E. Bosse, and D. A. Lambert, High-Level Information Fusion Management and Systems Design, Artech House, April 2012.

T5. An Introduction to Track-to-Track Fusion and the Distributed Kalman Filter

Speaker(s): Felix Govaers (Fraunhofer)

Duration: 3 hours

Abstract: The increasing trend towards connected sensors ("internet of things" and "ubiquitous computing") derive a demand for powerful distributed estimation methodologies. In tracking applications, the "Distributed Kalman Filter" (DKF) provides an optimal solution under certain conditions. The optimal solution in terms of the estimation accuracy is also achieved by a centralized fusion algorithm which receives either all associated measurements or so-called "tracklets". However, this scheme needs the result of each update step for the optimal solution whereas the DKF works at arbitrary communication rates since the calculation is completely distributed. Two more recent methodologies are based on the "Accumulated State Densities" (ASD) which augment the states from multiple time instants. In practical applications, tracklet fusion based on the equivalent measurement often achieves reliable results even if full communication is not available. The limitations and robustness of the tracklet fusion will be discussed. At first, the tutorial will explain the origin of the challenges in distributed tracking. Then, possible solutions to them are derived and illuminated. In particular, algorithms will be provided for each presented solution. The list of topics includes: Short introduction to target tracking, Tracklet Fusion, Exact Fusion with cross-covariances, Naive Fusion, Federated Fusion, Decentralized Fusion (Consensus Kalman Filter), Distributed Kalman Filter (DKF), Debiasing for the DKF, Distributed ASD Fusion, Augmented State Tracklet Fusion.

T7. Title: Deep Convolutional Neural Networked-based Multisensor Fusion for Computer Vision: Opportunities and Challenges

Speaker(s): Fahimeh Farahnakian (University of Turku)
Duration: 3 hours
Abstract: Deep Convolutional Neural Network (DCNN) has been developed as one of the main models in deep learning and successfully applied to a wide range of computer vision tasks showing state-of-the-art performance. For this reason, most multisensor fusion architectures for computer vision tasks are built based on DCNN. In addition, DCNNs have great potential in processing the multisensory data, which usually contains rich information in the raw data and is sensitive to training time as well as model size. However, the multisensor fusion approaches suffer from two challenges, which are (1) the feature extraction from various types of sensory data and (2) the selection of a suitable fusion level. Generally, these approaches can be divided into three main groups based on the level of data abstraction used for fusion: early fusion, middle fusion and late fusion. In the early fusion, also called pixel-level fusion, the raw sensor data are combined to generate a fused data before applying any information extraction algorithms. In the middle fusion, also called feature-level fusion, the extracted features from each raw data are fused. In the late fusion, also called decisionlevel fusion, the detectors are independently applied to each sensor and then their results are combined to make final detection. In this tutorial, we will introduce the trend of DCNN-based multisensor fusion architectures: early, late and middle fusion. We will discuss how they are employed for three main computer vision tasks: classification, detection and segmentation. The talk covers methods and principles behind these architectures for target classification, target detection, instance segmentation, and semantic segmentation. We will talk about advantages and disadvantages of these architectures. Finally, we will illustrate this taxonomy through relevant examples from the literature and will highlight existing open challenges and research directions that might inspire attendees to embark in the fascinating and promising area of DCNN-based multisensor fusion methods. Attendees to this tutorial will leave with a good sense of how multi-sensor fusion technology can be used for a range of computer vision research tasks.

T8. Practical use of Belief Function Theory: Tools and examples of applications

Speaker(s): Sylvie Le Hégarat-Mascle (Paris Saclay University)
Duration: 3 hours
Abstract: In the first part of the presentation (1h), I will recall the main tools of Belief Function (BF) framework to handle imprecise and uncertain information. I will start with the basic operators defined in the seminal book of Shafer (1976), before presenting more recent

developments and interpretations (from Smets' transferable belief model to Pichon's work about the modelling of the quality of the sources). Now, although the theory of belief functions has been widely popularized in the past two decades, there are still difficulties when implementing it in complex applications. Then, in the second part of the presentation, I will focus on illustrating the usefulness of belief function tools. I will firstly illustrate the benefit of the conflict estimation (1/2h). I first present different measures of conflict from empty set mass to Destercke's work or Pichon's one. Then, I illustrate its benefit for GNSS (Global Navigation Satellite System) localization in a constrained environment, for which multi-path propagation phenomena, for example, generate outliers. Secondly, I illustrate (1/2h) the benefit of modelling the partial ignorance (when it occurs). Thirdly, I will consider the case of large discernment frames (1/2h). Indeed, a drawback often stressed is the increase of complexity (basically in 2N for N hypotheses), when using BF. Then, I discuss different solutions: from Denoeux' one to handle multidimentionality discernment frames to the one we proposed in the context of monitoring pedestrians from a multi-camera system. Finally (1/2h), I will introduce the available library (2CoBel) that allows to handle usual BF as well as BF defined on 2D discernment frame as presented in the last application.

T9. Multisensor Data Fusion for Industry 4.0

Speaker(s): Claudio M. de Farias (Federal University of Rio de Janeiro), José F. B. Brancalion (EMBRAER S.A.)
Duration: 3 hours

7. **Abstract:** The Internet of Things (IoT) is a novel paradigm that is grounded on Information and Communication Technologies (ICT). Recently, the use of IoT has been gaining attraction in areas such as logistics, manufacturing, retailing, and pharmaceutics, transforming the typical industrial spaces into Smart Spaces. This leads to a novel paradigm called Industry 4.0. Since IoT data is usually dynamic and heterogeneous, it becomes important to investigate techniques for understanding and resolving issues about data fusion in Industry 4.0. Employment of Data fusion algorithms are useful to reveal trends in the sampled data, uncover new patterns of monitored variables, make predictions, thus improving decision making process, reducing decisions response times, and enabling more intelligent and immediate situation awareness. This tutorial aims to show the multisensory data fusion techniques used in the Industry 4.0 scenario as well
as case studies.

T10. Evaluation of Technologies for Uncertainty Reasoning

Speaker(s): Paulo Costa (George Mason University), Kathtyn Laskey (George Mason University), Gregor Pavlin (Thales)

Duration: 3 hours

Abstract: The ETUR Tutorial will explore three topics: (1) summarize the state of the art in uncertainty analysis, representation, and evaluation, (2) introduce the main aspects of the Uncertainty Representation and Reasoning Framework (URREF), and (3) explain its use via a series of case studies that apply the framework. The impact to the ISIF community would be a tutorial exploring the overal topic of uncertainty representation and evaluation. In addition to the theoretical background on the topic, the audience will be exposed to a number of use cases that have been part of the ongoing discussions within the ISIF Working Group that created the framework. Among the subjects covered, the attendees will have some guidelines to draft requirements documentation, the gain of fusion systems over current uncertainty representation techniques, as well as issues that are important in information fusion systems designs. One of the main goals of information fusion is uncertainty reduction, which is dependent on the representation chosen. Uncertainty representation differs across the various levels of Information Fusion (as defined by the JDL/DFIG models). Given the advances in information fusion systems, there is a need to determine how to represent and evaluate situational (Level 2 Fusion), impact (Level 3 Fusion) and process refinement (Level 5 Fusion), which is not well standardized for the information fusion community. This tutorial will introduce a framework developed to address these issues.

T11. Estimation of Noise Parameters in State Space Models: Overview, Algorithms, and Comparison

Speaker(s): Ondřej Straka (University of West Bohemia), Jindřich Duník (University of West Bohemia)

Duration: 3 hours

Abstract: Knowledge of a system model is a key prerequisite for many state estimation, signal processing, fault detection, and optimal control problems. The model is often designed to be consistent with random behavior of the system quantities and properties of the measurements. While the deterministic part of the model often arises from mathematical modeling based on physical, chemical, or biological laws governing the behavior of the system, the statistics of the stochastic part are often difficult to find by the modeling and have to be identified using the measured data. Incorrect description of the noise statistics may result in a significant worsening of estimation, signal processing, detection, or control quality or even in a failure of the underlying algorithms. The tutorial introduces a more than six decades-long history as well as recent advances and the state-of-the-art of the methods for estimation of the properties of the stochastic part of the model. In particular, the estimation of state-space model noise means, covariance matrices, and other parameters is treated. The tutorial covers all major groups of the noise statistics estimation methods, including the correlation methods, maximum likelihood methods, covariance matching methods, and Bayesian methods. The methods are introduced in the unified framework highlighting their basic ideas, key properties, and assumptions. Algorithms of individual methods will be described and analyzed to provide a basic understanding of their nature and similarities. Performance of the methods will also be compared using a numerical illustration. The attendees will be provided with course notes and sample implementations of the selected methods.

T12. Stone Soup: an open source tracking and state estimation framework; principles, use and applications

Speaker(s): Steven Hiscocks, Jordi Barr, Paul Thomas, Richard Green (Defence Science and Technology Laboratory, UK), David Kirkland, Bhashyam Balaji (Defence Research and Development Canada), Lyudmil Vladimirov, Simon Maskell (University of Liverpool, UK)
Duration: 6 Hours
Abstract: It is currently difficult and time consuming for academic researchers to recreate state-of-the-art tracking and state estimation algorithms to benchmark their work. Comparison of new algorithms with existing solutions involves recoding algorithms from the literature. Industrial users also find it difficult to assess which algorithms meet their, often quite varied, requirements. The Stone Soup framework is designed to provide a flexible and unified software platform for researchers and engineers to develop, test and benchmark a variety of existing multi-sensor and multi-object estimation algorithms. It is also designed to allow rapid prototyping of new algorithms in high-level languages, both open and proprietary (e.g. Python, Matlab), as well as development in compiled languages (e.g. C++), by providing a set of libraries which implement the necessary functions for tracking and state estimation. It profits from the object-oriented principles of abstraction, encapsulation and modularity, allowing users (beginners, practitioners or experts) to focus only on the most critical aspects of their problem. Stone Soup is endorsed by ISIF's working group on Open Source Tracking and Estimation (OSTEWG). This tutorial will introduce participants to Stone Soup's basic components and how they fit together. It will be delivered by way of demonstrations, set tasks and interactive sessions where participants will be encouraged to write and modify algorithms. These tasks will be written up in the form of interactive browser-based applications which combine the ability to run code with a presentation environment suitable for instruction. The tutorial will begin with basic examples using linear transition models,

abstract range-bearing sensors and single-targets using the extended and unscented Kalman and particle filters. Multiple targets, clutter and methods of data association will be introduced. The second session will cover several applications using real-world data, advanced algorithms and will connect with other methods of inference/classification (for example deep learning-based video processing). The outputs of this tutorial are likely to be highly relevant to the Open Source Tracking and Estimation Working Group, whose annual meeting will take place during the Fusion conference.

T13. Fusion using belief functions: source reliability and conflict

Speaker(s): Frédéric Pichon (Université Artois), Anne-Laure Jousselme (NATO STO CMRE)
Duration: 3 hours
Abstract: Information fusion is one of the key applications of the theory of belief functions (aka evidence theory or Dempster-Shafer theory), as shows the regular sessions on belief functions at the FUSION conference. This tutorial will provide an opportunity for students and researchers to learn about fundamental and advanced aspects of the multi-source (either sensors or humans) information fusion within the theory of belief functions. Rather than surveying the different combination rules, this tutorial will specifically address the problem of combining information from partially reliable sources, explaining how to properly use meta-knowledge about the sources reliability in the fusion process. A general approach to information fusion will be presented, allowing going beyond reliability such as truthfulness and reinforcing the relevance of belief function theory for information fusion. Means to tackle practical fusion problems will also be provided. When meta-knowledge about the source reliability is not available, the validity of assumptions on the source reliability can be evaluated thanks to the notion of consistency. One interpretation of the conflict (or lack of consistency) between sources is indeed that it is due to the unreliability of some of the sources involved in the reasoning. The second part of the tutorial will present recent advances on the measurement of consistency and conflict in evidence theory. A family of measures of consistency extends the consistency between sets and brings under the same umbrella existing measures while defining new ones, offering a finer characterization of conflict. The related and often associated notion of distance will be also presented, highlighting links, similarities and differences with conflict. Each theoretical concept will be illustrated on examples from several applications mainly from the maritime domain.

T14. Poisson multi-Bernoulli mixtures for multiple target tracking

Speaker(s): Ángel F. García-Fernández (University of Liverpool), Yuxuan Xia (Chalmers University of Technology)
Duration: 3 hours
Abstract: 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 that has been applied to data from lidars, radars, cameras and 5G networks. In addition, the attendant will learn the relations of the PMBM filter with other MTT algorithms such as multi-Bernoulli mixture (MBM) filter, probability hypothesis density (PHD) filter, Poisson multi-Bernoulli (PMB) filter, delta-generalised labelled multi-Bernoulli (GLMB) filter, multiple hypothesis tracking (MHT), and joint integrated probabilistic data association (JIPDA) filter. Finally, this tutorial will cover the extension of the PMBM filter to sets of trajectories to represent full trajectory information from the information received from the sensors.

T16. Context-enhanced Information Fusion

Speaker(s): Lauro Snidaro (University of Udine), Erik Blasch (AFRL)
Duration: 3 hours
Abstract: Contextual Information (CI) can be understood as the information that "surrounds" an observable of interest. Even if not directly part of the problem variables being estimated by the system, CI can influence their state or even the sensing and estimation processes themselves. Therefore, understanding and exploiting CI can be a key element for improving the performance of Information Fusion algorithms and automatic systems in general that have to deal with varying operating conditions. There is a growing interest for this promising research topic that should be considered for developing next-generation Information Fusion systems. Context can have static or dynamic structure, and be represented in many different ways such as maps, knowledge-bases, ontologies, etc. It can constitute a powerful tool to favour adaptability and boost system performance. Application examples include: context-aided surveillance systems (security/defence), traffic control, autonomous navigation, cyber security, ambient intelligence, ambient assistance, etc. The purpose of this tutorial is to survey existing approaches for context-enhanced information fusion, covering the design and development of information fusion solutions integrating sensory data with contextual knowledge. After discussing CI in other domains, the tutorial will focus on context representation and exploitation aspects for Information Fusion systems. The applicability of the presented approaches will be illustrated with real-world context-aware Information Fusion applications.

T17. Robust Kalman Filtering

Speaker(s): Florian Pfaff (Karlsruhe Institute of Technology), Benjamin Noack (Karlsruhe Institute of Technology)

Duration: 3 hours

Abstract: The optimality of the Kalman filter does not only depend on an accurate, linear model but also on perfectly known parameters of the prior and noise distributions. This requirement is not special to the Kalman filter but is rather an inherent problem deeply rooted into Bayesian filtering and, in parts, also frequentist statistics. The attendants will learn how this problem can be overcome by using hybrid approaches that rely on a combination of stochastic and set-membership methods. The approach is thoroughly explained along with solutions to new challenges arising. Furthermore, using the example of event-based estimation, the attendants will learn how these versatile approaches not only help to improve our modeling of the true uncertainty but also help to make use of the absence of information.

T18. Localization-of-Things: Foundations and Data Fusion

Speaker(s): Moe Z. Win (MIT), Andrea Conti (University of Ferrara)

Duration: 3 hours

Abstract: The availability of real-time high-accuracy location awareness is essential for current and future wireless applications, particularly those involving Internet-of-Things and 5G communication networks. Reliable localization and navigation of people, objects, and vehicles Localization-of-Things is a critical component for a diverse set of applications including connected communities, smart environments, vehicle autonomy, asset tracking, medical services, military systems, and crowd sensing. The coming years will see the emergence of network localization and navigation in challenging environments with sub-meter accuracy and minimal infrastructure requirements. We will discuss the limitations of traditional positioning, and move on to the key enablers for high-accuracy location awareness: wideband transmission, cooperative processing, and data fusion. Topics covered will include: fundamental bounds, cooperative algorithms, and network experimentation. Fundamental bounds serve as performance benchmarks, and as a tool for network design. Cooperative algorithms are a way to achieve dramatic performance improvements compared to traditional non-cooperative positioning. To harness these benefits, system designers must consider realistic operational settings; thus, we present the performance of cooperative localization based on measurement campaigns.

T21. Deep Feature Learning to Model Brain Network Activities

Speaker(s): Narges Norouzi (University of California, Santa Cruz)
Duration: 3 hours
Abstract: This tutorial is on deep feature learning to analyze and identify different brain activities. We will discuss: 1) Time-Frequency analysis of EEG signals using Morlet Wavelet and ShortTime Fourier Transform techniques, 2) Pre-processing techniques for EEG signals including an introduction to Generative Adversarial Network (GAN) architecture for noise removal (generating Stereo EEG-like signal from EEG readings), 3) Feature learning using 2-D and 3-D Convolutional models, and 4) Understanding propagation pattern of a brain activity in the map of the brain using multi-modal recurrent deep architecture. The goal of the tutorial is to help the audience build knowledge about state-of-the-art techniques for identifying a brain activity or predicting the onset of an activity. They then should be able to use these multi-scale approaches to extract mathematical and statistical features to elucidate detailed anatomic information regarding the initiation, propagation, and termination of different neural activities.