# REASONING AND OBJECT-ORIENTED DATA PROCESSING FOR MULTISENSOR DATA FUSION

Advanced information technologies provide indispensable contribution to peacekeeping and other crisis response operations. Sensor grids, flexible communications networks and Web-based services provide for early warning, increased situational awareness, shorter decision cycles and flexible use of force. Remote, or 'stand-off,' monitoring saves lives. Unattended ground, sea and air sensor systems become vital tools for sensing movement or presence of persons, vehicles, weapon platforms and armed force formations in their vicinity. Alerting peacekeepers in a timely manner, modern sensor systems are the main source of information for adequate situation and treat assessment and for rapid deployment of force.

Number of commercial-off-the-shelf sensor systems already proved their efficiency in recent peacekeeping missions. Utilizing newly developed methods and computer hardware, they provide highly intelligent information processing, saving manpower and time. Despite considerable accomplishments in the field, the explosive growth of environmental complexity and uncertainty raise demands for higher degree of automation and more 'embedded intelligence.' Current technological advances in radar, infrared, electro-optical and laser sensors are paralleled by developments in image and data processing methods and systems to provide for effective monitoring.

The contest for efficient environmental sensing has focused current R&D on qualitatively new data processing methods and algorithms, thus establishing a new ground for efficient decision support, in particular for situation and threat assessment. The shift of scientific efforts in recent years towards advanced multisensor data fusion (MSDF) applications is of particular interest for the scientific community, and to the readership of '*Information & Security*.'

This issue of the journal presents latest achievements in two important and promising areas of Multisensor Data Fusion: (a) plausible and paradoxical reasoning in the context of state and parameters estimation and (b) object-oriented sensor data processing. Currently, there are two essential problems in the implementation of information processing systems. The first one stems from the lack of efficient algorithms for uncertainty management that is produced by the difficulties of

automatic knowledge processing. The second one is the problem of "productivity" of developed algorithms, demonstrated as acute shortage of productive computational resources. The common understanding of the scientific community is that the first problem might be overcome by developing a new theory of reasoning based on wiser understanding of human cognitive processes. The second problem is subject of active study by two groups of innovators: (a) algorithm developers, that provide computationally efficient algorithms, and (b) designers of super computers that successfully create new computational facilities and advanced computer networks.

Presenting reasoning methods and algorithms, we have the outstanding opportunity to present the article *Foundations for a new theory of plausible and paradoxical reasoning,* kindly provided for publication by Jean Dezert from ONERA, France. Introducing the readers into the new theory, the author presents an advanced rule of combining sources of information in a very general framework, where information can be both uncertain and paradoxical. In this new theory, the rule of combination, that takes into account explicitly both conjunctions and disjunctions of assertions in the fusion process, appears to be more simple and general than the Dempster's rule of combination. Through numerous examples the author demonstrates the strong ability of this new approach to solve difficult practical problems, where the Dempster-Shafer theory usually fails.

Another work in this area is the presentation of *Fuzzy Logic Approach to Estimating Tendencies in Target Behavior,* written by Albena Tchamova and Tzvetan Semerdjiev, both from the Central Laboratory for Parallel Processing of the Bulgarian Academy of Sciences. This approach exploits the existence of attribute data that is usually available simultaneously with kinematic data. The approach is promising in real-world situations when kinematic data is not available or is not sufficient to provide right decision or/and accurate estimates. The available data is usually incomplete, inconsistent and vague, so the problem of overcoming arising uncertainties in such cases is of high importance. The objective of the provided paper is to present an approach to estimate the tendency of target behavior. The respective algorithm is presented and evaluated in detail. Fuzzy Logic principles are applied to conventional passive radar amplitude measurements. A set of fuzzy models is used to describe the tendencies of target behavior. The authors apply a noise reduction procedure and, using computer simulations, estimate the performance of the developed algorithm in the presence of noise.

Discussing the reasoning methods and algorithms, we are unavoidably touching another important area of research interest - information integration. Today, two processes are commonly recognized as general tendencies of the social development – integration of the existing information systems in one global *System of systems* and mass transition of human mental functions to computer systems and robots.

Mankind's difficulties and the need of many scientists to solve them are the main reason for evolving global processes of information integration. Only a "*shortening of distances*" based on development of information technologies will make it possible to solve the problems of the 21$^{st}$ century using the power of the integrated human minds for efficient reasoning. One original view on this set of problems is presented in the article *The Genetic Program: A Technocratic Hypothesis on the Paradigm of Civilization*. The proposed hypothesis for the evolution of the human civilization examines primarily information and information technologies as components of the global technological program of the universal mind. Assuming the *a priori* existence of ontological information nucleus in the genetic code, inherited by new generations, the hypothesis offers an explanation of technology, processes, and realization of a global algorithm for mastering our part of space and time, building an eternal incubator of wisdom – a colony for accumulation of knowledge and reduction of entropy in the universe. Taking into account the impact of social factors in the global models, as well as the lack of universal concept for sustainable development, we ascertain an *acute paradigmatic deficiency*. The interpretation of the hypothesis in the framework of general historic window provides global classification of the phases of technological development of humanity as a metamodel. Evolving towards the information society, the human civilization naturally advances to new 'informational' forms of warfare, treated under this hypothesis as paradigmatic deformations in the global relationship between humanness and violence.

These three articles presented in the first section of the issue give an excellent opportunity to obtain a common view both on the concept of modeling human reasoning and on the concept of universal mind.

The second section of the issue is devoted to latest developments in object-oriented sensor data processing. Design, implementation, and assessment of computationally efficient tracking algorithms are essential part of sensor data processing that raises many complex problems. One way to alleviate these problems is to provide the designer with an environment, facilitating the creation of different test scenarios, automating implementation of algorithms and the evaluation of their measures of performance. Such an environment is a complex software program that could be simplified by using object-oriented design and programming. Unifying data and functions that operate on the data, the overall program organization can be improved. In their contribution *Object-Oriented Environment for Assessing Tracking Algorithms*, E. Djerassi and P. Konstantinova propose a set of classes divided into three groups considering the modeling part, the processing part, and the organization of the statistical analysis to assess performance.

Following the direction of efficient tracking algorithm design, the next paper *On the Generalized Input Estimation* by V. Jilkov and X. Rong Li from the Department of

Electrical Engineering in the University of New Orleans, US, presents some original assumptions. The "input estimation" (IE) is one of the competing methods for tracking maneuvering targets. The presentation aims to clarify the interrelation between the standard IE method and a recently proposed "generalized input estimation" (GIE). It is shown that the GIE can be obtained as a particular case of the conventional IE with a "constant input" and "time - varying transition matrix" of the input. This fact could be used in a straightforward manner for further optimization of existing GIE algorithms.

One original application of newly developed sensor data processing algorithms for tracking is presented in the paper *Contact Transitions Tracking During Force-Controlled Compliant Motion Using an Interacting Multiple Model Estimator*, contributed by a research team form the Katholieke Universiteit Leuven, Belgium. The work, which may be seen as spin-off of advanced defense research, addresses both monitoring of contact transitions and estimation of unknown first-order geometric parameters during force-controlled motions. A robotic system is required to move an object among a sequence of contact configurations with the environment, under partial knowledge of geometric parameters (positions and orientations) of the manipulated objects and of the environment itself. The authors consider a compliant motion task with multiple contacts, namely that of moving a cube into a corner. It is shown that by describing the contact configurations with different models and using the multiple model approach, it is possible: (a) to detect effectively current contact configuration and (b) to estimate accurately the unknown parameters. The reciprocity constraints between ideal reaction forces and velocities are used as measurement equations. An Interacting Multiple Model (IMM) estimator is implemented and its performance is evaluated based on experimental data.

The following two papers directly address the problem of computational load. L. Bojilov from CLPP-BAS presents *An Improved Version of an Algorithm for Multiple Targets Tracking*. Some of the well-known data association rules and algorithms are changed and carried out. Performing an exhaustive set of experiments, the author shows that his algorithm provides a plausible alternative to the well-known algorithms for finding the first K-best hypotheses. Currently, the obtained result is prepared for implementation in the framework of the Multi Hypothesis Tracking approach, potentially allowing for new applications of these computationally intensive algorithms.

Similar achievement is reported in the contribution of L. Bojilov, K. Alexiev, and P. Konstantinova on *An Accelerated IMM-JPDA Algorithm for Tracking Multiple Maneuvering Targets in Clutter*. Theoretically, the most powerful approach for tracking multiple targets is known to be Multiple Hypothesis Tracking (MHT) approach. However, it leads to combinatorial explosion and computational overload.

By using an algorithm for finding the K-best assignments, the MHT approach can be optimized in terms of computational load. A much simpler alternative of the MHT approach can be the Joint Probabilistic Data Association (JPDA) algorithm combined with Interacting Multiple Models (IMM) approach. Even though it is much simpler, this approach can be computationally overwhelming as well. To overcome this drawback, an algorithm due to Murty and optimized by Miller, Stone and Cox is embedded in IMM-JPDA algorithm for determining a ranked set of K-best hypotheses instead of all feasible hypotheses. The presented algorithm assures continuous maneuver detection and adequate estimation of maneuvering targets in heavy clutter. This results in a good overall target tracking performance with limited computational and memory requirements. The corresponding numerical results are presented in the article.

*Specific Features of IMM Tracking Filter Design* is considered in the paper provided by Iliyana Simeonova and Tzvetan Semerdjiev. As the interacting multiple model (IMM) algorithm is one of the most cost–effective and simple schemes for tracking maneuvering targets, so the knowledge of the specifics of its design is important to achieve more accurate parameter estimates. This paper presents the specifics of the IMM tracking filter design. Results, conclusions and experience of different authors have been generalized. Through this investigation the user is provided with a fast and easy way to determine advantages and the potential of different IMM structures given the target motion scenario. In addition, the behavior of three IMM configurations has been studied, using a specially developed MATLAB tool.

Today, computer simulation is an important instrument for design, analysis, and testing of complex systems, whose state and parameters cannot be easily estimated. Such simulation includes input data generation, modeling of system dynamic, and state estimation with proper result visualization. The most complex target tracking algorithms can be easily coded in Matlab environment. The Matlab language can be learnt quickly and provides high productivity for algorithm design and evaluation. This set of issues is discussed in the article *A MATLAB Tool for Development and Testing of Track Initiation and Multiple Target Tracking Algorithms*, contributed by Kiril Alexiev. The author describes a particular simulation tool for design and analysis of radar data processing systems. Its architecture and techniques are organized around the main stream of the process of algorithms generation, simulation, analysis and evaluation. It is reported that this is an effective instrument, which could be of benefit for radar data processing specialists and scientists.

For those, interested to learn more about the problems considered in this issue, we present a list of selected recent publications. Some of them present in-depth studies of the multi target tracking problem. Others contain thorough examination of latest achievements and description of particular implementations. Useful references and

considerable number of papers, devoted to MSDF, is available on the Internet site of the Bulgarian Information Society Center of Excellence for Education, Science and Technology in the 21st Century. Brief information about one particular work package of this center, named "Real-time Data processing in Adaptive Sensor Interfaces," is also presented. We find these publications useful for students, specialists and PhD applicants involved in the study of MSDF. Additionally, a short list of Internet links is given for everyone who is interested in latest news.

We hope this issue will help to develop new interrelations within the MSDF research community. The common interest in solving information processing problems using MSDF technologies will provide new opportunities for fruitful cooperation and consideration of future joint R&D projects.

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