Habilitation thesis - Information Processing in Distributed Sensor Systems

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Abstract

Recent advances in the design of complex networked sensing systems bring challenges for managing the flow of information over hierarchical levels of data processing. With direct impact on large scale monitoring and automation systems, the development of new algorithms for sensor data pro- cessing represents a timely issue that can improve the performance of the control loops by means of high level data-driven abstraction layers. Distributed sensing by wireless sensor and actuator nodes provides the opportunity of fine grained actions in both temporal and spatial domains. The underlying information system architecture that supports the transformation of data from the sensor measurements of the physical world is an important component, especially while accounting for new paradigms such as fog computing to serve as middleware within a flat automation hierarchy composed of only field level/intelligent periphery devices, and cloud/decision level. Key applications of distributed sensor systems, critical and non-critical, are currently focused on the built environment, smart cities and industry.

The habilitation thesis structure has been divided into three main parts. The first part, in Chapter 1, covers my professional background with emphasis on the seven-year period between 2013 and 2019, reflecting the activity within the Department of Automatic Control and Industrial Informatics at the University Politehnica of Bucharest after the defence of my PhD thesis. This has been carried out mainly within the Industrial Information Systems group while also enjoying fruitful collaboration with several other depart- ment colleagues and external collaborators. Research projects where I have served as principal investigator have been funded by the European Commission through the human resources development program, the US Department of State through the US-Romania Fulbright Commission, the Austrian Academy of Sciences, the Ministry of Research and Innovation and the University "Politehnica" of Bucharest, as well as private companies. During this time, the teaching activity consisted of delivering course and practical activities in information processing, intelligent measurement systems and control engineering. Engagement with the scientific community at large has been a guiding factor of my career so far through the involvement in the organisation of important scientific events, journal editorial boards and conference program committees, volunteering activities within professional organisations and as external expert for public and private entities.

The second part of the thesis, covered by Chapters 2 through 4, includes an extensive survey of the main scientific achievements illustrated by recent publications. This has been roughly divided into the following areas of original contributions. The first area has been concerned with new **consensus algorithms for distributed agreement in sensor networks**. In this case work has been done to study and optimise network and communication topologies, in conjunction with the physical system being monitored, that helps these distributed sensor agents to reach agreement on values or actions of joint interest. On top of this data aggregation and eventually sensor fusion primitives have been applied and provide inputs to higher level decision layers. **Smart building automation**, including model predictive control and black-box modelling of building energy dynamics, has been a second key area of research. Using computational intelligence techniques on pre-processed data streams collected from the building, including new developments such as deep neural networks for sequence modelling, mitigates several challenges in the identification of building dynamics through time consuming and costly approaches. This has been applied both to thermal energy as well as electrical energy consumption of large commercial buildings. Finally, the design of **industrial information system** architectures that support higher level developments using open-software and hardware modules has been a further area of activity. The availability and dissemination of such design patterns is a key enabling factor of reproducible research by means of open datasets, code libraries and other types of artefacts. It is important to note that many of the original contributions have been realised in teams that already include PhD students and postdoctoral researchers.

The final chapter of the thesis elaborates upon the research perspectives that are supported by previous and current ongoing work. The main interests are foreseen to lay with building robust distributed sensor systems with efficient management of computing, communication and control resources under the Cyber-Physical Systems (CPS) and the industrial Internet of Things (IIoT) paradigms. This will account also for the emergence of statistical learning algorithms and contributing to their implementation and experimental validation for *in situ* detection, forecasting and performance optimisation in automation. The current research plans offer good potential to improve and develop new teaching activities with emphasis on PhD and master study programs and international cooperation frameworks.
Future key objectives are thus summarised as follows:

- strengthening of a research team in the field of distributed sensor data processing and learning algorithms for control applications, with outreaching economic and social benefits;

- enabling new PhD students to independently and critically pursue and develop up-to-date research questions, supported by experimental engineering achievements;

- assuring the means and infrastructure to drive good quality research, impact and visibility of the results at an international level, thereby contributing to the consolidation the scientific prestige currently enjoyed by the University Politehnica of Bucharest.

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