Integration of Industry 4.0 concepts in processes control

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Habilitation thesis
Summary

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Before presenting the main research domains which I followed after ending my doctoral studies, I will present the steps I took in **my academic career**. My background is based on an engineer's diploma in automation and computer science issued in 2002 by the University Valahia of Targoviste, Romania. In 2005 I defended my Ph.D. thesis in control engineering "Contribution to low voltage electrical networks with distributed renewable energy generation control (PD- RES) using fuzzy controllers" at Politechnica University of Bucharest, under the guidance of professor Sergiu Stelian Iliescu.

Industry 4.0 represents the trend towards automation and data exchange in manufacturing technologies and processes which include cyber-physical systems (CPS), the internet of things (IoT), industrial internet of things (IIOT), cloud computing, cognitive computing and artificial intelligence. Often referred to as a smart, connected factory, this is the synthesis of a convergence between automation and the Internet.

The Internet of Things (IOT) and large volumes of data are the core of Industry 4.0. The virtual world and the real world converge. Data and connectivity are its two bases that lead to growth and development. Thus, based on the automation of production and the interconnection of its processes, there is an integrated system of equipment, machines, employees, mobile devices and IT systems, all of which are capable of communicating with each other.

Thus, integrating the concepts of Industry 4.0 into the implementation of a complete production management system (MES) is one of the most important steps and involves four stages:

- Digitization - access to real-time data. The right software solution makes it possible to digitize information and to quickly transmit it to the entire production process.

- Mobility - connecting operators to computer systems for process control.

- Automation - organization of production processes by interconnecting machines, machines, equipment and devices and connecting all these resources to IT solutions.

- Systems integration - the use of a computer system that integrates horizontally and vertically both physical resources (machines, equipment, employees, etc.), as well as execution processes (process control, data flow control, quality assurance, resource management, equipment maintenance, interfacing with equipment).

The habilitation thesis is entitled "Integration of Industry 4.0 concepts in processes control" and represents a synthesis of the scientific activity that I carried out after obtaining the title of Doctor in 2009. In this framework, the research activities carried out during my career are mainly related to:

1**. Intelligent control of systems with distributed power from renewable energy sources (PD-SER) (areas of interest: digitization, mobility and system integration);**

2. Control of the autonomous mobile systems (areas of interest: digitization and automation);

3. Design, simulation and control of flexible manufacturing lines served by complex autonomous systems (areas of interest: digitization, mobility, automation and system integration).

The thesis is structured on four parts, as follows: the three research directions and a future development plan.

1. Intelligent control of systems with PD-SER

Estimates regarding the amount of energy produced from renewable energy sources (SER) and consumption, at some point in the future, represent for the integrated energy management system information that decisively contributes to the efficient management of energy. The extra information brought by their integration in the low voltage electricity grids with distributed production from renewable energy sources (PD - SER) optimizes the sharing of resources between consumers and gives the grid a "smart grid". Considering the benefits, of economic nature but also related to the security of the network, which can bring them the integration of the prediction in the control and monitoring techniques, the scientific community is manifesting its interest in this field more and more.

PD of electricity in low voltage networks plays a very important role in current research worldwide, generating intense concerns due to both the beneficial effects and certain technical problems that need to be solved in order to benefit from these effects. Specifically, by producing electricity locally, the loss of distribution on the lines can be compensated but at the same time an excess of power can cause overvoltage leading to the instability of the network.

The research carried out by me as project director in this direction includes the specific outcomes and results of the project "**Intelligent decision support system for the low voltage grid with distributed power generation from renewable energy resources**", Cod: PN-II-PT-PCCA-2011-3.2-1616. The consortium was composed by Valahia University of Targoviste (UVT), Advanced Technology Systems (ATS) and Politehnica University of Bucharest (UPB).

The research activity aimed at optimizing the consumption and generation of energy in a low voltage network with PD- SER, by creating and implementing a dedicated intelligent decision support system. It integrates the decision theory and concepts of artificial intelligence into the actions of monitoring, supervision, prediction and control and allows its users, through the information provided, to control the electricity consumption of the devices used to reduce the invoiced costs, carbon emissions, energy demand. during peak periods and the efficient use of SER.

The decision support application proposed is accessible to any interested user through the project site (http://indesen.ats.com.ro/) which provides also general information regarding the project, the activities carried out during its development as well as technical information regarding at RJT with PD- SER created and implemented at Valahia University in Targoviște, project coordinator. The validation of the proposed software tool was performed on an experimental model by RJT with PD- SER. The innovative character and complexity of the project are given by the integration of the elements of artificial intelligence in the prediction of the energy consumption and the amount of energy from the SER produced.

In this research context, I was in charge with the following research and innovation activities:

a. Fundamental research activity regarding the components of the intelligent decision support system in the field of PD from SER

- Documentation regarding the application of the methods and techniques of artificial intelligence in the control of low voltage networks with distributed production (PD-SER)
- Documentation regarding the development of methods and techniques for predicting the possible states of local network functioning
- Comparative analysis regarding the application of the methods and techniques of monitoring and control of low-voltage networks

b. Modelling, simulation and design of the hardware components of the functional model of the

intelligent decision support system

- Modeling and simulation of photovoltaic generators
- Simulation of a low voltage electrical grid with production from photovoltaic sources
- Designing the components of the intelligent decision support system in the field of PD-SEER
- Elaboration of the algorithm for predicting the power generated and consumed by each element in the RJT with PD-SER

c. Development of an intelligent decision support system

The research activity in this field was materialized by the publication of articles and the participation in international conferences. I present bellow five of the most important dissemination actions:

Dragomir F., Dragomir O., Minca E. - *A Fuzzy Approach to Intelligent Control of Low Voltage Electrical Networks with Distributed Power from Renewable Resources*, Proceedings of the IEEE International Energy Conference and Exhibition (EnergyCon'10), pg: 606 – 611, 18-22 December 2010, Manama, Bahrain

Dragomir O.E., **Dragomir F.**, Stefan V., Minca E. - *Adaptive Neuro-Fuzzy Inference Systems as a Strategy for Predicting and Controlling the Energy Produced from Renewable Sources*, Energies, 8(11), pp. 13047-13061, 2015

Dragomir O.E., **Dragomir F.**, Stefan V., Minca E. - *Adaptive Neuro – Fuzzy Inference Systems – an Alternative Forecasting Tool for Prosumers*, Studies in Informatics and Control, Volume 24, Issue 3, pp. 351-360, 2015

Dragomir F., Dragomir O.E., Iliescu S.St., Brezeanu I., Stănescu I. - *Assessment of photovoltaic panels heath using a LabView object oriented application,* Proceedings of the 2014 International Conference on Control Engineering and Automation (ICCEA2014), pp. 711-716, 2014

Dragomir O.E., **Dragomir F.,** Radulescu M. - *Matlab Application of Kohonen Self- Organising Map to Classify Consumers' Load Profiles*, Procedia Computer Science, Volume 31, Pages 474–479, 2014

Dragomir F., Dragomir O.E. - *Distributed Power Generation from Renewable Energy Resources*, Proceedings of UKSim-AMSS 6th European Modelling Symposium on Mathematical Modelling and Computer Simulation (EMS2012), 14 – 16 November 2012, Valletta, Malta, Page(s): 299 - 304, 2012

2. Control of the autonomous mobile systems

The research carried out by me as project director in this direction includes the specific outcomes and results of the projects: „**A New On-Chip Magnetically-Actuated Mobile Microrobotic Agent and Embedded Control System**", Cod: PN-II-RU-PD-2012-3-0591 and "**Mobile microrobotic system for single-cell manipulation and sorting (RoBoCell)**", Cod: PN-III-P2-2.1-PED-2016-1675.

All the activities aimed at the first instance the design and practical realization of an innovative mobile microrobotic structure, followed by the design and realization of a mobile microrobotic system for the manipulation / sorting of original single-cell organisms.

Mobile microrobotic system was built and controlled automatically in magnetic field. The micro-robot itself has dimensions of the order of 180 μm x 250 μm x 300 μm and evolves in an arena of only 2x3 millimetres.

In the activity of designing and realizing a mobile microrobotic structure, my research activities have focused on:

a. study of the existing approaches regarding the design and the methods of actuation and control of

the microrobots respectively (The operating principles of the microrobotics, The possibilities of microfabrication)

b. experimental and theoretical studies on the design, simulation and development of the micro-robot (Finite element simulations (fields, dynamics), Design of the micro-robot structure (functional description of the proposed micro-robot), Design of the workspace (arena), Development of the micro-robot and a two-dimensional workspace consisting of conductive tracks (arena). Creating the micro-robot, Making the workspace (arena),

c. testing the microrobotic system (the individual arena and the arena-agent assembly) and designing the electronic control circuit

In the activity of designing and creating a mobile microrobotic system for the manipulation / sorting of unicellular organisms, my research activities have focused on:

a. the study of micromanipulation systems for bio-medical applications, of microrobotic systems for bio-medical applications and studies on microfabrication options;

b. design, simulation and realization of the mobile microrobotic system for the manipulation / sorting of unicellular organisms. Implementation of the control algorithm;

c. testing of the mobile microrobotic system for the manipulation / sorting of unicellular organisms (testing of the system being carried out in the laboratories of the University of Medicine and Pharmacy "Carol Davila" of Bucharest).

This research direction was materialized by participating in international microrobotics competitions, patent filing (mobile microrobotic system for handling / sorting of single-celled organisms), publication of articles and participation in international conferences. I present bellow five of the most important dissemination actions:

Dragomir F., Ivan I.A., Gurgu I.V., Radulescu N.G., Bucurica I.A., Dulama I.D. – 7 First Prises in Mobile Microrobotics Challenge in 2015, 2016, 2017 and 2018. IEEE Robotics and Automation Society First Prise in ”Autonomous Mobility & Accuracy Challenge”, ”Microassembly Challenge” și ”MMC Showcase & Poster Session Winner”. The International Conference on Robotics and Automation (ICRA), Seattle 2015, Stockholm 2016, Singapore 2017 and Brisbane 2018.

Gurgu I.V., **Dragomir F.**, Radulescu N.G., Dulama I., Bucurica I.A., Ivan M.E. - *Mobile micro-robotic system for manipulating unicellular organisms comprises a motion arena supported by a platform*, Oficiul de Stat pentru Invenții și Mărci (OSIM), **Patent Number(s):**RO132431-A0, **Derwent Primary Accession Number:** 2018-24701J, **Derwent Class Code(s):** P62 (Hand tools, cutting (B25, B26).), **International Patent Classification:** B81B-005/00; B25J-007/00

Dragomir F., Ivan I.A., Gurgu I.V., Radulescu N.G., Bucurica I.A., Dulama I.D. - *Comsol simulation of electromagnetic field required for a microrobot actuation*, Journal of Science and Arts, 2(43), pp. 523-529, 2018

Dragomir F., Dragomir O.E. - Microrobotics: Present, Challenges, Perspectives, Proceedings of the 2014 IEEE International Conference on Robotics and Biomimetics (RoBio2014), pp. 1904 – 1909, 2014, Bali, Indonesia

3. Design, simulation and control of flexible manufacturing lines served by complex autonomous systems

The research carried out by me as research team member in this direction includes the specific outcomes and results of the ongoing project : **“Intelligent and distributed control of 3 complex autonomous systems integrated into emerging technologies for medical-social personal assistance and servicing of precision flexible manufacturing lines (CIDSACTEH)**”, preciselly Project 4

„**Modelarea, simularea și conducerea în timp real a liniilor de fabricație asistate de sisteme autonome complexe (SAC-ARP, SAC-VAM) integrate în tehnologii hibride de fabricație flexibilă de precizie, de laborator (linii de mecatronică) și industriale, pentru produse reutilizabile”**, Cod: PN-III-P1-1.2-PCCDI-2017-0290 .

The research carried out within this research direction has led to the design of models and the collection of simulation data for precision flexible manufacturing lines, integrated into hybrid manufacturing, assembly / disassembly (A/D) technologies with integrated autonomous systems (SAC). The model was design for the flexible manufacturing line located in the laboratory of Valahia University in Targoviște, is composed of 5 workstations. The line is assisted by an autonomous complex system - personal robotic assistant (SAC-ARP) equipped with manipulator and an autonomous complex system - multidirectional autonomous vehicle (SAC-VAM) used for the transport of the processed piece. Taking advantage of the modelling and simulation results, the disassembly station was designed, as well as the robotic manipulation platform, for flexible manufacturing.

At the end of the project, the manufacturing line will be flexible and reversible and additional modules will be added to the actual configuration, like a distributed network of sensors and visual servoing systems.

In this research context, I was in charge with the following research and innovation activities:

a. Design and implementation of the disassembly control structure in a dedicated position

b. Designing and implementing the automated control structure of flexible manufacturing on a dedicated mechatronic line;

c. Achieving hardware compatibility between the flexible assembly/ disassembly manufacturing line and the movement / transport / manipulation of the SAC;

d. Integration into the control structure of precision flexible manufacturing lines, complex SAC control structures and configurations distributed by sensors and servoing systems;

e. Real-time control of flexible manufacturing lines for precision assembly and disassembly;

The research activity in this field was materialized by the publication of articles and the participation in international conferences. I present bellow five of the most important dissemination actions:

Dragomir F., Mincă E., Dragomir O.E., Filipescu A. - *Modelling and Control of Mechatronics Lines Served by Complex Autonomous Systems*, Sensors, Vol. 19, Issue 15, Article Number 3266,

Minca E., Filipescu A., Coanda H.G., **Dragomir F.**, Dragomir O.E., Filipescu A. - *Extended Approach for Modelling and Simulation of Mechatronics Lines Served by Collaborative Mobile Robots*, Proceedings of the International Conference on System Theory, Control and Computing – ICSTCC 2018, Page(s):335 – 341, 2018

Dragomir F., Caramida M.S., Dragomir O.E., Minca E. - *Towards neural control of the mobile robots*, Journal of Science and Arts, Vol. 19, Issue 2, pp. 529-540, 2019

Minca E., Coanda H.G, **Dragomir F.**, Dragomir O. Filipescu A. - *Cycle time optimization of a reversible A/DML served by a mobile robotic system*, Proceedings of the 19th International Conference on System Theory, Control and Computing, (ICSTCC), pp. 99 – 104, 2015

4. Perspectives for the development of research activities

Taking into consideration the research and teaching activities performed so far, I believe that I can outline a personal development strategy that will allow me to advance in many domains of scientific and academic interest.

In the research direction " Intelligent control of systems with PD-SER " I intend to submit a new proposal, in connection with the theme, within the Horizon 2020 competition. This approach will allow further improvement of hardware infrastructure of RJT with PD-SER.

In the research direction „Control of the autonomous mobile systems" I intend to develop the prototype of the microrobotic system, conceived in MicRoMag and RoBoCell research projects and to attract new financing sources participating in national and international calls (Tinere echipe, Proiect experimental demonstrativ, Parteneriate, Horizon 2020).

In the research direction „Design, simulation and control of flexible manufacturing lines served by complex autonomous systems" I intend to continue and complete the research activities within the CIDSACTEH research project. The autonomous robotic system will be simulated trough kinematic and dynamic models for which advanced control algorithms will be designed (sliding-mode control and backstepping). These algorithms will ensure to the model robustness to perturbations and uncertainties. Autonomous robotic systems equipped with robotic manipulators will serve flexible reversible manufacturing lines for assembly/ disassembly and reprocessing, respectively. For robotic systems, the algorithms of control in collaborative mode will be developed based on the theoretical concepts developed previously.

Scientific collaborations

Currently, I am affiliated with the Electrical Engineering, Electronics and Information Technology Faculty, Automation, Computer Science and Electrical Engineering Department (DAIIE-FIEETI) where I carry out my didactic activity and to the Energy-Environmental Research Department from Multidisciplinary Scientific and Technological Research Institute (DCEM-ICSTM).

The complexity of the research areas addressed in my scientific activity allowed me to collaborate with teams of researchers from : Polytechnic University of Bucharest, "Franche-Comté" University of Besançon France, National Institute for Research and Development in Computer Science, National Institute of Research and Development for Electrical Engineering ICPE-CA, "Dunărea de Jos" University Galați and University of Craiova.

All the collaborations in which I am actively involved are carried out within the research projects won through national competitions. Consequently, the results obtained have mainly innovative aspects. In this respect, I can mention :

- control of low voltage electrical networks with distributed production from renewable energy sources - collaboration with the Polytechnic University of Bucharest, the research group coordinated by Prof. ing. Sergiu Stelian Iliescu (outcome my PhD thesis)
- intelligent decision support systems applied in low voltage electrical networks with distributed production from renewable energy sources - research in collaboration with the Department of Automation and Industrial Informatics, the Faculty of Automatic and Computers, the "Politehnica" University of Bucharest
- intelligent modelling of the dynamics of renewable energy production / consumption - research in collaboration with the National Institute for Research and Development in Informatics
- mobile microrobotic system with magnetic control - research in collaboration with the MIMENTO Department at the FEMTO Institute - ST, Besançon, France
- autonomous robotic systems for the medical-social assistance and the control of some

manufacturing processes - research in collaboration with the Department of Automatic and Electrical Engineering, the University "Dunărea de Jos" from Galati, the Department of Automatic and Industrial Informatics, the Faculty of Automatic and Computers, the University " Politehnica "from Bucharest and the University of Craiova.

The results obtained and the fields of competence allowed me, at the same time, to collaborate with the private environment:

• Advanced Technology Systems (ATS) – partner in the field of intelligent decision support systems;

• ICPE SA – partner in the field of distributed production from renewable energy sources;

• Electro-Total Bucharest, Department of Industrial Automation – partner in the field of autonomous robotic systems intended for medical-social assistance and for the service of manufacturing processes