Appendix No 2B

Summary of professional accomplishments

presenting an overview of accomplishments and scientific achievements in particular referred to in article 16 §. 2 of the Act on Academic Degrees and Title and Degrees and Title in the Arts.

PhD Ireneusz Dominik

Contents:

1. Name and surname

Ireneusz Dominik

2. Diplomas and scientific degrees specifying the name, place and year they were obtained as well as the title of the doctoral

- **Title: Technician of electronics**
  Techniczne Zakłady Naukowe w Dąbrowie Górniczej
  Specialization: electric and electronic industry automatics
  Place and year of graduation: Dąbrowa Górnicza, 1996 r.

- **Degree: Master of science**
  AGH University of Science and Technology,
  Faculty of Mechanical Engineering and Robotics, Department of Process Control
  Field of study: Automatics and Robotics
  Specialization: Automatics and Measurement
  Place and year of graduation: Kraków, 2002 r.

- **Degree: PhD Doctor of Engineering**
  AGH University of Science and Technology,
  Faculty of Mechanical Engineering and Robotics, Department of Process Control
  Field of study: Automatics and Robotics
  Specialization: Mechatronics
  Thesis title: Control of line driver based on shape memory effect
  Place and year of graduation: Kraków, 2007 r.

  Thesis distinguished with honors by the resolution of the Board of the Faculty of Mechanical Engineering and Robotics of the AGH University of Science and Technology

3. Information on previous and current employment

- 01.10.2002 r. - 31.05.2008 r. assistant in the Department of Process Control of the Faculty of Mechanical Engineering and Robotics, AGH University of Science and Technology
- 01.05.2008 r. assistant professor in the Department of Process Control of the Faculty of Mechanical Engineering and Robotics, AGH University of Science and Technology

4. Scientific achievements

Scientific achievements pursuant to art. 16 §. 2 of the Act of 14 March 2003 on Law on Academic Degrees and Title and Degrees and Title in the Arts (Official Journal of Laws 2016 item 882 as amended).

4.1. The title of scientific achievement

monograph:
"Type 2 algorithms in mechatronics systems control"

4.2. The Author, title, year, publishing house, reviewers

Ireneusz Dominik
"Type 2 algorithms in mechatronics systems control"
Year: 2017, Publishing house of AGH University of Science and Technology, ISBN 978-83-7464-893-6

Reviewers:
Janusz Starczewski, associate professor
Institute of Computational Intelligence Faculty of mechanical Engineering and Computer Science, Czestochowa University of Technology
Krzysztof Oprzędkiewicz, associate professor
Department of Automatics and Biomedical Engineering, Faculty of Electrical Engineering, Automatics, Computer Science and Biomedical Engineering,
AGH University of Science and Technology

4.3. Characteristics of the scientific achievement

The first person who introduced the concept of fuzzy logic in 1965 was Lofti Zadeh. That concept was an alternative to the classical definitions of set theory and logic deriving from the times of ancient Greek philosophy. It was formed from the need to describe complex phenomena or poorly defined definitions, difficult to be described by use of classical mathematical methods.

The introduction of fuzzy sets was accompanied by criticism and numerous doubts, as on the one hand they define uncertain definitions while on the other hand the values of membership functions are precise, as they are described by specific parameters. It seemed to be contrary with the very fuzzy concept and the problem of defining limits of a function and uncertainty of e.g. measurement has still remained. Zadeh answered this question himself, when 10 years later in 1975, he proposed a more practical type of fuzzy sets, i.e. fuzzy sets Type-2, which served as generalization of the classical Type-1. It is of course possible to further generalize and create the concept of the fuzzy sets of a higher order, but in practice such sets are not used as they cause great difficulties in interpretation, visualization and a great computational effort is required during their processing.

In Type-1, x- element is characterized by a degree of membership to a fuzzy set, which is a real number, whereas in Type-2 a degree of membership is fuzzy. This concept reduces the impact of inaccuracy of control system work caused by subjective opinions of experts, where the knowledge collected from several experts on the premises and conclusions (forming the basis of rules) is not the same, as the same linguistic terms are defined differently by individual experts. What is more, the fuzzy logic Type-2 occurs to be much more effective when taking into account uncertainty.

There are five basic types:

- Uncertainty of measurement – error of noticeable size,
- Uncertainty of processes – the randomness of dynamics,
- Uncertainty of the model – wrong specification of the model structure,
- Uncertainty of approximation – uncertainty which may derive from any of the above-mentioned inaccuracies or its combination, commonly known as lack of precision or inaccuracy,
- Uncertainty of implementation – a consequence of volatility that results from the sorting method, i.e. inability to achieve the exact purpose of the strategy.

After the fuzzy logic Type-2 was defined for the first time, there was a long period during which researchers focused on logic Type-1, easier for interpretation, implementation and not requiring a high processor power. It was not until the 90s of XX century when scientists returned to the fuzzy logic Type-2. Dubois and Prade were the first scholars who proposed a concept of a function of a secondary membership. They recognized that fuzzy sets Type-2 should be used in case the linguistic uncertainty of a variable cannot be fully modelled by a fuzzy set Type-1. Karnik and Mendel defined the reduction algorithm of Type-2 to Type-1 required to calculate the output value. The first book" Uncertain Rule-Based Fuzzy Logic System: Introduction and New Directions" dedicated to fuzzy logic Type-2 written by Mendel was published in 2001. In 2003 the fuzzy logic Type-2 began to be used in control systems, for example in process systems of liquid flow, mobile robots and large diesel marine engines.

Despite the relatively short history, more than 80 thousand works in worldwide literature were related to the topic of fuzzy control type-2, which confirms the great interest among science centers and legitimacy of this issue. The reason for introducing fuzzy sets of Type-2 was first and foremost the fact that knowledge used to create them takes uncertainty into account. Despite its name, the fuzzy logic is based on strict laws and rules, but uses data that are inaccurate and imprecise. As a result, the knowledge gained from several experts is ambiguous. At the same time it should be taken into account that measurement signals are disrupted. In the real-world systems, processes of aging and wearing of the parts are included in the uncertainty of mathematical model parameters. Control systems which are based on fuzzy sets Type-1 are not able to take into the account the uncertainty of this kind, in contrast to systems based on fuzzy sets Type-2, which are characterized by additional fuzzied membership function.

The main aim of this work is to present the possibility of applying fuzzy algorithms Type-2 in controlling mechatronic systems. The presented results are based on the research of the author.

In recent years, growth in computing power of applied processors enables the implementation of more complex fuzzy algorithms Type-2. Therefore, the aim focuses on demonstrating the superiority of algorithms of fuzzy control Type-2, taking into account the above mentioned uncertainty over algorithms Type-1 in selected mechatronic systems. Obtaining satisfactory indicators of the regulation quality for hard-to-operate objects forces building their accurate mathematical models, requires a lot of workload for complex control systems and is not always guaranteed as possible.

The use of algorithms in the area of computational intelligence, less intuitive in comparison to the classical control, does not require knowledge of these models. At the same time it is reasonable to use fuzzy control for objects, where performance of classical control system with PID controller is difficult or impossible. Many years of author's experience gained during designing systems with fuzzy controllers Type-1, showed high usefulness of their application to hard-to-operate mechatronic objects, but does not take uncertainty into account. Therefore, the development of tools supporting the design process of fuzzy controllers Type-2 will facilitate their application and will bring this topic towards a larger group of scientists and engineers.

This paper concerns the use of computational intelligence that applies fuzzy algoirthms Type-2 in order to control seven real-world mechatronic systems. In addition, the work contains a description of proprietary software environments commonly used in the design of control systems: Matlab and LabVIEW. The toolboxes were tested in the design and simulation works:

- Fuzzy predictive control Type-2,
- Analysis and comparison of the performance of reduction algorithms Type-2,
- Filtration of the disrupted signal in ANFIS system Type-2.

In addition, the use of toolboxes for rapid prototyping was proposed, based on automatic code generation program for a wide range of controls:

- PLC,
- Microprocessor platform Arduino,
- System of programmable gate array FFGA.

The designed tools shortened the deployment time of control systems and allowed tuning a control loop during simulation tests. Automatic code generation that eliminates human factor, reduces the risk of errors in the code. It is worth noting that the latest version of Siemens software, which will be released at the beginning of 2017, enables automatic generation of the code for controller's series S7 1200 and 1500, which are now the number one driver in Poland and Europe. In addition, the ability to simulate the type of Hardware-in-the-Loop was tested, in which the object model and controller code are simulated in the procesor control unit. This method is often used before starting and testing the control system of the hard-to-operate real object, protecting from damage or destruction.

The next chapter focuses on describing the use of the previously mentioned proprietary toolboxes allowing for versatile use of fuzzy controllers Type-2 in engineering practice. The first two paragraphs outline the implementation of fuzzy controllers Type-2 in PLC Siemens drive to control the object position during magnetic and air levitation. These objects are strongly nonlinear – they have a considerable dead band, saturation and hysteresis. The nature of the objects made it possible to compare the performance of the whole controller's series: PID, fuzzy Type-1 with TSK and Mamdani models and Type-2 with the same TSK and Mamdani models, and the reduction of alpha plane type. The analysis of the received processes and compiled values of quality regulation shows that the best results were obtained using a TSK controller Type-2. For all references in the position of magnetic levitation, the regulation times and delays were the shortest, and also the values of integral IAE were the lowest. In case of air levitation, the TSK regulator Type-2 had the smallest oscillations around the set point. The test indicates that this controller is easy to be implemented and has a code-friendly algorithm, which allows shortening the cycle time of less than 1ms.

In another real-world system, inverted pendulum, the fuzzy sliding controller Type-2 was used. The built mathematical model of the pendulum and the use of proprietary toolbox IT2FLS made it possible to conduct simulation tests and automatic generation of the code to B&R in a real object control. Among the six implemented controllers, the sliding controller with fuzzy switching function and fuzzy sliding controller FSMC Type-2 were used. The performed studies with documented processes and calculated quality controller indicators of the implemented controllers confirmed that, by far, the best controllers were fuzzy sliding controllers FSMC. They are characterized by high resistance to disturbing moment along with elimination of chattering and reducing the value of overshoot. FSMC controller Type-2 had also a shorter regulation time compared to the FSMC controller Type-1.

In the following sections of this paper, the control of position and pressure force of the robot gripper are presented. In order to construct the gripper, the wire actuator with shape memory alloy (SMA) was used. SMA actuators can serve as artificial muscles and be used in the construction of the mentioned gripper or the prosthesis with many degrees of freedom. The motivation drive was the establishment of cooperation with Department of Orthopedic Equipment in Kraków in 2015. It is the largest manufacturer of medical prostheses in Poland, which ordered construction and control of the active hand prosthesis and research on neurosurgical robot designed for stereotactic brain surgery, conducted at the department of Process Control at AGH university. At the same time the author of the monograph has partnered with the Miga Motor company, which put the disposal of the whole series of SMA actuators, free of charge, for research purposes. The design of the actuator constructed on SMA wires has the highest weighing factor (the ration of the weight load and their own) among all commercially available actuators. In addition, it does not generate vibrations or noise, it is easy to build and cheap to operate. The SMA wires are used in the control mostly as a two-state (on /off) unit because of the strong nonlinearity and nonstationarity of SMA material, which results in difficulties with setting intermediate position and force control. To control two types of actuators: series NM70 and DM01, RISC microprocessor AT mega32 and PLC controller by B&R were used. The general fuzzy controller Type-2 with asymmetrical function of secondary membership occured to have very good control times during controlling the position of the actuator for both hot and cold SMA wires. A sectional fuzzy controller Type-2 occurred to be better than general during the test of the gripper pressure force control.

The next step was the implementation of the fuzzy controller Type-2 in the Single-Board RIO 9636, based on the FPGA architecture and the real-time processor, to the smart control of the servo-pneumatic manipulator. Pneumatic actuators performance in a linear manner is normally realized by means of pneumatic cylinders, which in industry most commonly performs precise linear displacement of the object. They are characterized by high work safety, low sensitivity to ambient temperature and are distinguished by low weight and price, as well as being easy to maintain during operation. The pneumatic servo driver for controlling the actuator uses pneumatic servo valves in which the performance characteristics are predistortion signal, the presence of dead zone, and asymmetry. It means that depending on the direction of the valve, the voltage change by the same amount causes another change in the flow rate. The implemented fuzzy controller Type-2 using the previously described toolbox had better positioning accuracy compared with fuzzy controller and PID controller. What is more, it distinguished itself by the smallest disparity at work in both directions and the most repeatable trajectory.

The last chapter presents a genuine solution of the simplified fuzzy controller Type-1 and 2 made in analogue technology. The analog regulators use a continuous analog signal in response to the continuous input signal and does not have the limitations of sampling signal, which are the digital controllers. Therefore, they can be used where difficulties in achieving short sampling time occurs. Two electronic circuits for operational amplifiers were built, where all stages of operation of the fuzzy controller Type-2 were realized: blurring, inference and sharpening with the reduction type. The built system has been tested to control the position of SMA actuator. The quality of regulation indicator was achieved satisfactory and the ability to create different shapes of membership function allow easy tuning of regulators. The applied analog technique enables the realization of fuzzy control of different types of objects at a low cost of the purchased electronic components.

The conducted experiments confirm that the use of fuzzy controller Type-2 brings tangible benefits in the form of accurate positioning, position stabilization and force control in the mentioned deployment works. The use of fuzzy algorithms Type-2, despite a higher degree of computational complexity is justified. In case, where the PID controller cannot control the object in satisfactory manner, the fuzzy controller Type-1 in comparison to other controllers, does not need mathematical models to perform properly. The study also proves that after the construction of the controller Type-1, it can be easily extended to the interval controller Type-2 and gain higher quality control with little effort. In such cases, the track width of uncertainty may be selected by the value of measurement error of the sensor.

Currently, the researches related to the application of fuzzy controllers Type-2 are moving towards the implementation of the general membership functions and the search for efficient algorithms of reduction type, which will allow in future to apply them in real-time control systems and their further popularization.

The work concerns the area of computational intelligence, which increasingly uses the fuzzy controller and neural networks.

The research carried out and presented in the published work of my contribution to the represented scientific discipline include:

- Proprietary software to design fuzzy controllers Type-2 commonly used in Matlab and LabVIEW environments,
- The use of toolboxes for design work and simulation such as: fuzzy predictive controllers Type-2, analysis and comparison of the performance of algorithms such as reduction, filtering the disrupted signal with ANFIS system Type-2,
- The use of toolboxes for rapid prototyping, based on automatic code generation program for a wide range of control devices such as: PLC, microprocessor Arduino platform, integrated programmable gate array FPGA,
- The use of toolboxes for automatic code generation program for simulating hardware-in-the-loop, wherein the object model and the controller code are simulated in the processor of controlled device,
- Versatile use of fuzzy controller Type-2 in the practice of engineering realized for 7 different real objects, demonstrating the improvement of the quality of regulation to both conventional PID and fuzzy controllers for Type-1,
- The original design solution of fuzzy controllers Type-1 and Type-2 realized in analog technology,
- Demonstration of easy modification of the controller type-1 to the interval controller Type-2 which improves the quality control with little work effort,
- Creation of function blocks for B&R and Siemens controllers, which allows easy and rapid implementation of the interval fuzzy controller Type-2 in industrial conditions.

The achievements make a significant contribution to the scientific discipline of Automation and Robotics, both in Poland and in the world.

4.4. Other scientific and research achievements

My publication record includes 76 scientific papers and 4 patents (Tab.1). In recent years, I focused on the publication of my achievements in significant and reputable journals. Among them, 10 publications are indexed in the Journal Citation Reports database (JCR) and have a high Impact Factor (IF). It is worth noticing that I have a lot of experience in cooperation with industry realizing a number of implementation projects and I was a contractor in 11 research projects. My scientific work and research were confirmed in December 2016 when the project Tango 2 jointly implemented by NCN and NCBiR of which I am a supervisor received funds.

Tab. 1. My scientific achievements

Type of publication:	**Number**	**Notes**	**MNiSW points** for a publication year
Indexed in Web of Science Core Collection	23	e.g. IF journals and conference materials	Account in Scientific publications
Indexed in Journal Citation Reports (JCR) with Impact Factor (IF)	10	• **IF = 11,692** for a publication year (Impact Factor), • **IF = 13,761** 5 Year Impact Factor • Citations in Web of Science (WoS): **32** • h-index in Web of Science (WoS): **4**	230
Patents	4		108
Monographs and academic handbooks	5		60
Scientific publications (reviewed)	61		257
			Sum: **655**

*detailed description available in Appendix 3

Kraków 24.01.2017

Dominik