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TEZĂ DE DOCTORAT

Contribuţii la controlul inteligent al roboţilor autonomi echipaţi cu sisteme multi-senzori

Contributions to intelligent control of autonomous robots equipped with multi-sensors systems

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Contents

Chapter 2

Intelligent control strategies for autonomous robots equipped with multi-sensor systems

2.1.1. Key concepts of Extenics Theory

To be able to manipulate the outcomes of situations which represent contradictory problems, we need to have in place a representation, as well as a set of tools and an environment model in which to do so. This section will briefly explain the theoretical basis of Extenics and describe the general model of thought in an Extenics problem. The three pillars of Extenics Theory are Basic Element, Extension Set and Extension Logic.

Extenics Theory maps all components of a given problem into elements, which provides the basis for a working model of the problem. These are called Basic Elements and consist of the triplet formed by an object, action or relation, a possibly infinite number of characteristics and their corresponding value relating to the object. In mathematical form, we call:

$$B = \begin{pmatrix} O_m & c_{m_1} & v_{m_1} \\ & \vdots & \vdots \\ & c_{m_n} & v_{m_n} \end{pmatrix} = (O_m, c_m, v_m)$$

a basic element in Extenics Theory. The 'm' means this particular triplet defines a matter-element (although all basic elements are similar from a construction standpoint) [67].

Extension Set Theory is a new set theory which aims to describe the change of the nature of matters, thus taking both qualitative, as well as quantitative aspects into account. The theoretical definition for an extension set is as follows: supposing U to be an universe of discourse, u is any one element in U, k is a mapping of U to the real field I, T=(TU ,Tk, Tu) is given transformation, we call:

$$E(T) = \{(u, y, y') | u \in U, y = k(u) \in I, T_u u \in T_U U, y' = T_k k(T_u u) \in I\}$$

an extension set on the universe of discourse U, y=k(u) the Dependent Function of E (T), and y'= T_k k(T_u u) the extension function of E(T), wherein, T_U, T_k and T_u are transformations of the respective universe of discourse U, Dependent Function k and element u. This is further illustrated in Figure 2.1 [67].

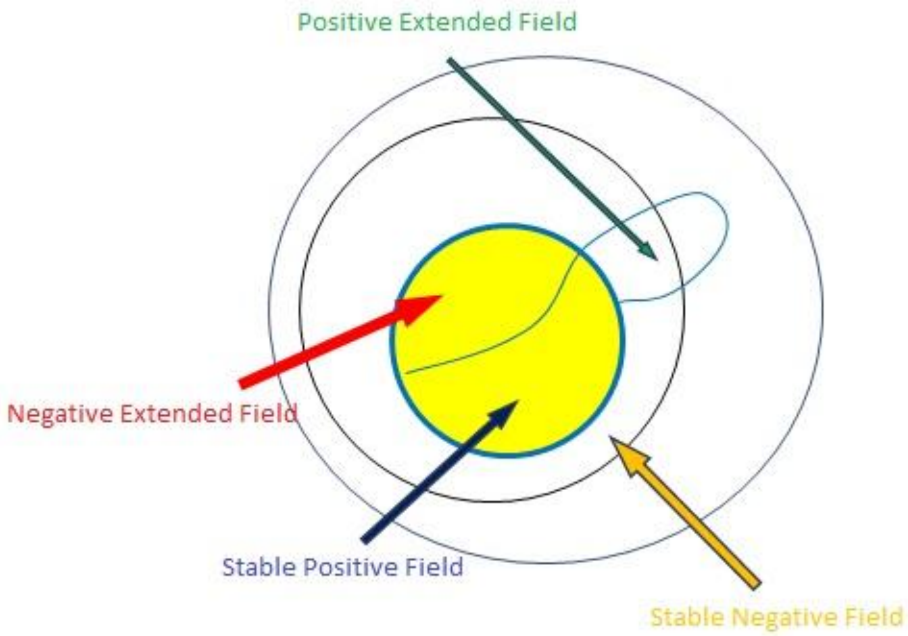

Figure 2.1. Universe of Discourse in an Extenics Transformation

With the aim of measuring the degree of compatibility or incompatibility in a given problem set, Extenics Theory has introduced the notion of Extenics Distance. New concepts of "distance" and "side distance" which describe distance are established, to break the classical mathematics rule that the distance between points and intervals is zero if the point is within the interval. The Dependent Function established on the basis of this can quantitatively describe the objective reality of "differentiation among the same classification" and further describe the process of qualitative change and quantitative change [67].

Extenics Distance extends the classical mathematic distance between a point and an interval to include a non-zero value for points inside the interval itself. In normal mathematics, the distance from a point inside and interval to that interval is always null, whereas in Extenics a point inside an interval is considered to have a negative distance to the interval. Suppose x is any point in real axis, and $X=<a,b>$ is any interval in real field, then:

$$\rho(x,X) = \left|x - \frac{a+b}{2}\right| - \frac{b-a}{2} \quad (2.8)$$

is the Extenics Distance between point x and interval $<a,b>$, where $<a,b>$ can be an open interval, a closed interval, or a half-open and a half-closed interval X. This is, in effect, the distance between the point considered and the closest border of the interval. It can be noticed that when the point is on the border of the interval (i.e. $x=a$ or $x=b$), the value at the interval limits is $\rho(a) = \rho(b) = 0$, while the global minim of the Extenics distance is at the centre of the interval, where its value is:

$$\rho\left(\frac{a+b}{2}\right) = -\frac{b-a}{2}. \quad (2.9)$$

Chapter 3

Stability of Autonomous Movement on Rough and Unstructured Terrain for Robots Equipped with Inertial Multi-Sensor Systems

3.1. Control of autonomous robots through the Zero Moment Point (ZMP) Method

As part of the undertaken research, a strategy was developed for the dynamic control of autonomous robot walking using ZMP and inertial information [26, 31, 49, 104]. The control strategy includes the generation of walk-compliant models, real time ZMP compensation in a single phase – the support phase, control of the leg joint dampening, control of stable walking and step position control based on the angular speed of the robot body. Thus, the humanoid robot becomes capable to adapt on rough terrain, through real time control without losing walking stability.

3.1.1. Real time balance control.

The real time equilibrium control strategy consists of 4 types of online control loops, respectively:

- *Damping control, for the elimination* of oscillations appearing in the single support phase [26, 49, 82,107]. This oscillation is measured mainly by the force/couple sensor placed in the joint as a compliant part of the moving structure.

For the robot motion model is used the equation of a simple inverted pendulum with one joint in the support phase.

- *ZMP Compensator*. Because the damping loop is insufficient to maintain a stable walk to the ZMP motion, a ZMP compensator is conceived for the single support phase (FSU). ZMP is established by the ZMP compensator according to the ZMP dynamic seen of the simple inverted pendulum with a corresponding joint, in which the platform moves back and forth.

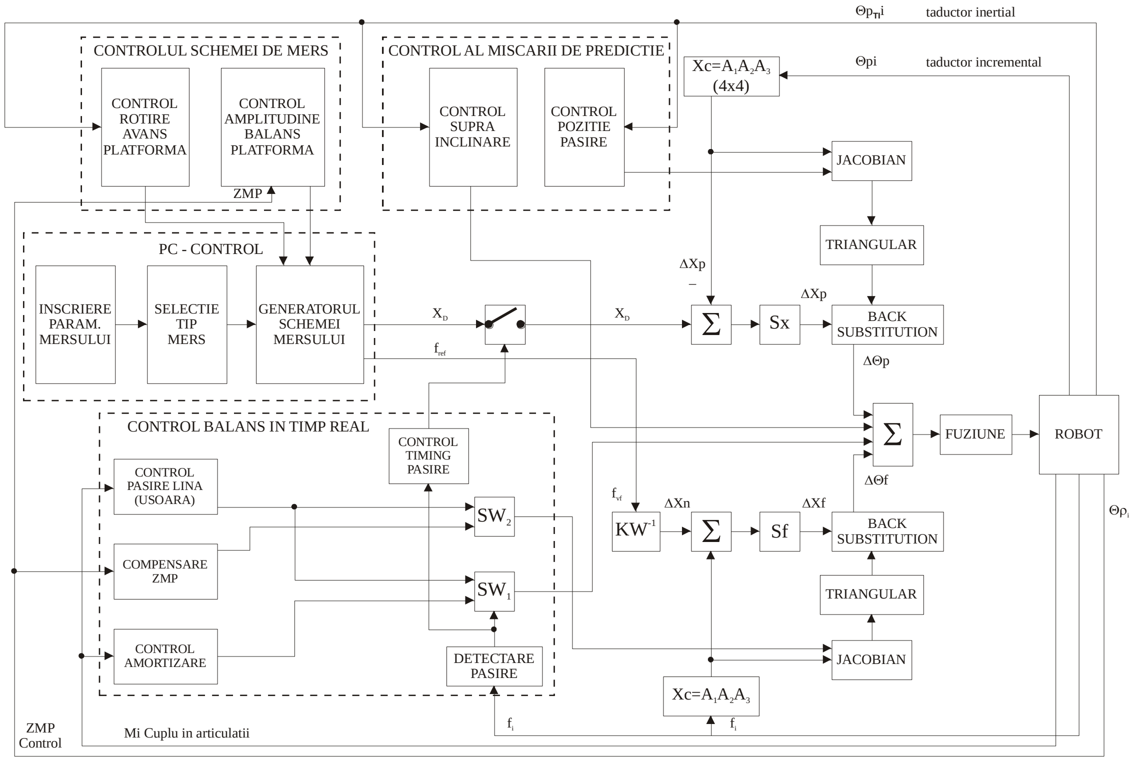

Figura3.4. Control roboțilorautonomiprinmetoda ZMP și a momentuluiinerțial

- *Landing orientation control.*For a smooth landing it is necessary to control landing orientation and step timing [15, 26, 27, 49, 78]. Easy landing orientation control is done by integrating the measured couple on the entire step duration. Stable contact is obtained by adapting the robot joints to the ground surface, in case an obstacle is met which precludes the robot leg motion after a normal trajectory in accordance with the walking strategy. Control of this movement will lead to easy and smooth stepping.
- *Step timing control***.** Step timing control for landing precludes the robot from becoming instable during landing by modifying the walking model. Thus, if the leg does not land on the ground at the end of phases 2 and 4, as is foreseen in the walking strategy, the timing control program in the overall control system will cease the motion until the leg makes contact with the ground.

Chapter 4

Extended Multi-Sensor Control of Autonomous Robot Movement

A method and device for the extension hybrid force – position control of the robotics and mechatronics motion systems was developed through applying the extended set from Extenics Theory to solving the contradictory problem of force-position control. Using this approach two contradictory elements, force and position, external to the classical control set, can become internal to the set through transformations, which will lead to solving the contradiction and the improving precision and stability of the robotics and mechatronics motion control. Results show an increase in the stability of the walking robots or mobile mechatronics motion control systems on plane, obstacle or uneven terrain, at constant or variable walking speed and constant or variable loads and of the tracking precision for the effectors element movement trajectory. This has found applications in nuclear material transport, agricultural activities, military applications in mine detection, lunar experiments and in general applications on uneven, inaccessible terrain, industrial robotic processes, MEMS (electro-mechanic micro-systems) applications, NMM (nano micro-manipulators) positioning applications, trajectory tracking, object manipulation and remote operation.

4.1.2 Modelling the position of the centre of gravity

For the movement and stability of walking robots on complicated terrain it is necessary to know the kinematic parameters of the centre of gravity of the walking robot (Figure 4.2). We note $Ox_Oy_Oz_O$ as the reference system of the robot. The geometric centre O is defined as central to the inscribed circle, while $G(x_{G,}y_{G,}z_G)$ is the robot centre of gravity. Taking into account the positions Xp_i, Yp_i, Zp_i of the robot legs we may develop a mathematical model which expresses the kinematic characteristics of the robot's centre of gravity. The Denevit – Hartenberg notations specified previously are valid, where Z_i^j (i=1,2 or 1,2, and j=1,3). We note m_i^j (i=1,2, j=1,3) as the masses of the leg mechanism elements. From the inverted kinematic model are known: θif . The $O_1x_1y_1z_1$ and $OO_xO_yO_z$ systems are solidary to the robot pelvis.

Transforming the coordinates of support point P_i in the $O_4x_4y_4z_4$ system to the $Ox_Oy_Oz_O$ system in order to determine the support polygon with respect to the platform is given in equation (4.4).

$$\begin{Vmatrix} 1 \\ X_0{}^i{}_P \\ Y_0{}^i{}_P \\ Z_0{}^i{}_P \end{Vmatrix} = A_0{}^i \cdot A_1{}^i \cdot A_2{}^i \cdot A_3{}^i \begin{Vmatrix} 1 \\ X_4{}^i{}_P \\ Y_4{}^i{}_P \\ Z_4{}^i{}_P \end{Vmatrix} \tag{4.4}$$

Transforming the coordinates of the centre of gravity for elements 1, 2, 3 of the leg mechanisms from their systems to the $O_O x_O y_O z_O$ system is obtained successively by passing from one degree of freedom to the next.

$$\begin{Vmatrix} 1 \\ X_0{}^i{}_{G4} \\ Y_0{}^i{}_{G4} \\ Z_0{}^i{}_{G4} \end{Vmatrix} = A_0{}^i \cdot A_1{}^i \cdot A_2{}^i \cdot A_3{}^i \cdot \begin{Vmatrix} 1 \\ X_{4\ Gi} \\ Y_{4\ Gi} \\ Z_{4\ Gi} \end{Vmatrix} \quad i=1,2 \tag{4.5}$$

The stability condition is that the vertical projection of the centre of gravity of the system G on the support surface be inside the support polygon. $A_O{}^i$, $A_1{}^i$, $A_2{}^i$, $A_3{}^i$ are given, where i=1.2 for the biped walking robot:

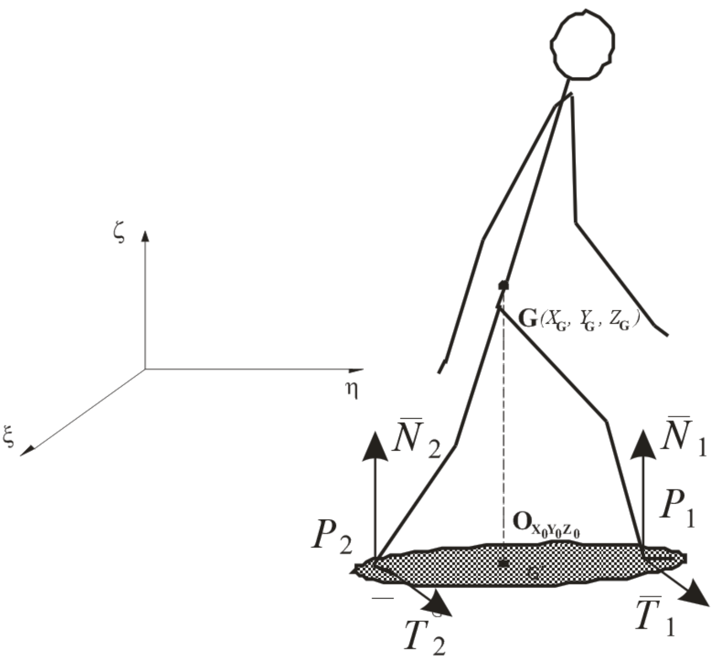

Figura 4.2. Mathematical modelling of the centre of gravity for biped robots

The centre of gravity positions for each element of the leg mechanism in relation to their own systems are known. The robot's centre of gravity position is determined by the coordinares, where X^K ={X, Y, Z} (k=1.2.3.):

$$X_G^k = \frac{m_0 \cdot X_O^k + \sum_{i=1}^{2}\sum_{j=1}^{3} m_j^i \cdot X^k \cdot G_j^i}{\sum_{i=1}^{2}\sum_{j=1}^{3} m_j^i} \tag{4.6}$$

Chapter 5

Navigation on Rough and Unstructured Terrain for Autonomous Robots Equipped with Multi-Sensor Systems

5.3. Intelligent neural networks modelling system for the information from an optical TOF scan laser

One of the challenges faced has to do with processing the information from the received photodiode signal. Figure 5.24 shows the multiple triggers used on the received signal. There is a certain threshold under which signal measurement is unreliable since it is mixed with environmental noise. The first of the triggers is therefore right above noise level, with the next two following shortly. This establishes the rising slope of the signal and can also be used for model verification. In this paper, these three levels will be used to estimate the actual measured distance. The fourth trigger is placed just above noise level on the falling slope and determines the end of the signal and thereby the total time of a meaningful received signal. This would work well for a one-time point scan, but in practice there is the danger of multiple returning signals (or even higher-amplitude noise) interpolating into a more complex reception input, which would make the fourth trigger unusable.

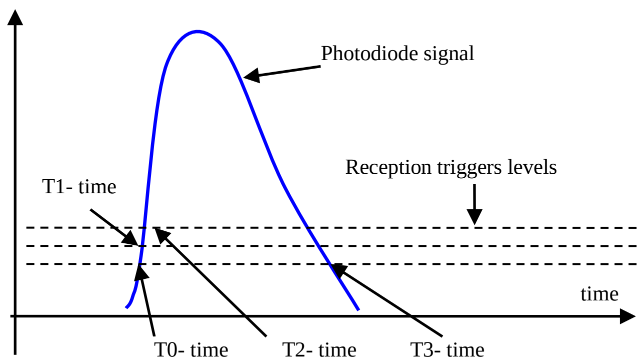

Figure 5.24. Triggers applied to the TOF scan laser signal

The measured distance is calculated as a function of the information obtained on the first (T0) and last (T3) triggers. Assuming T0 known, there is no difference in practice between knowing T3 and knowing the actual distance. Therefore the need to estimate the value at the fourth trigger level (T3) from the values obtained from the previous three (T0 – T2). The desired and expected results are finding the best estimation model for the fourth trigger value, which can be integrated into the optical scanner software at low computational expense and become part of the final before-market prototype.

Using artificial neural networks and regression implementations to model the information received from the sensor, an accurate reading of the measured distance can be obtained without the need for costly components. It also makes the scanner less susceptible to anomalous readings given by the interpolation of different wave signals. This is achieved by using the first three reception trigger signals for the returning wave to estimate the measured distance, rather than having to use a fourth trigger signal on the falling slope, which introduces dead time and may decrease performance due to wave interpolation.

There are a great number of methods which can be used to model such an approach [142]. The first step is to test the assumption using linear regression and neural networks on the mean values generated for each point at each of the four triggers. The work was done in the Octave software, as well as the artificial neural network toolbox in Matlab.

Linear regression with multiple variables is used for the first regression model. The problem is of the form

$$Y = \hat{\theta}X \qquad (1)$$
$$X = [X_1 X_2 X_3] \qquad (2)$$

where X is a matrix containing the values of the three known triggers (T0-T2) for all 250 space points, plus an intercept term. Y is a vector containing all space point values for the fourth trigger (T3) and Θ is a matrix of parameters which estimate Y from X. The issue revolves around finding the values of Θ which minimize the difference between the actual Y and the estimate obtained from the equation $\hat{Y} = \theta_{LR} X$ (3). The total sum of differences across all values is called the cost function (J).

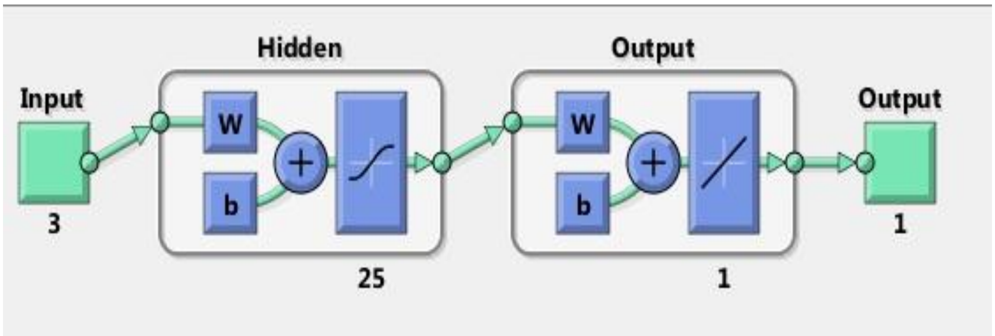

Figure 5.29. Artificial neuronal network with one hidden layer (25 neurons)

The final model used is a feed-forward artificial neural network model. An artificial neural network consists of a number of ‘hidden’ features (or neurons) associated with a network of weights, which are improved each iteration until their prognosis is within an accepted tolerance or the number of iterations expires. An example of the investigated network topographies is available in Figure 5.29.

From the available data, approximately 70% of the examples are used for the actual training of the network. Another 20% is used for cross-validation, whereby the weights are adjusted again based on the observed deviations. The remainder is used as a test for the obtained network, which provides a measure of its accuracy and of whether the network over-fits the available data.

By using the artificial neural network toolbox in Matlab with the obtained data and training a number of network configurations, as well as running through a variety of linear regression models, estimates were obtained for comparison with the actual mean values derived from the experimental data.

The results of the parameter estimation using linear regression with multiple variables and a trained artificial neural network can be seen in Figure 5.31.

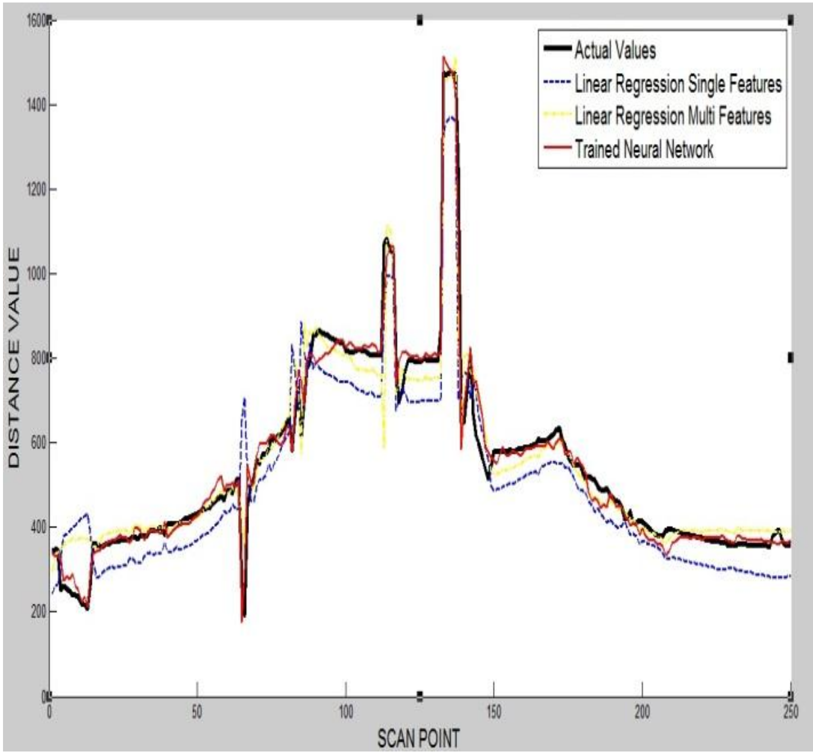

Figure 5.31. Comparison of real values (black) and estimates from all models

The end result is the selection of an artificial neural network to be implemented into the laser software with the trained weights obtained in the simulation. This will lead to faster and more robust results being obtained from the raw data, as well as the ability to run more tests using the prototype in actual situations (both static and dynamic).

The proposed Petri nets and Markov chains approach provides a promising solution towards the development quantitative approach of dynamic discreet / stochastic event systems of task planning of mobile robots. For a deeper insight into control and communication of governing task assignment of the robot, the entire discrete-event dynamic evolution of task sequential process have to be linguistically described in terms of representations.

This approach has the potential to model more complex relationships between target parameters. Moreover, the short time execution will ensure a faster feedback, allowing other programs to be performed in real time as well, like the apprehension force control, objects recognition, making it possible that the control system have a human flexible and friendly interface.

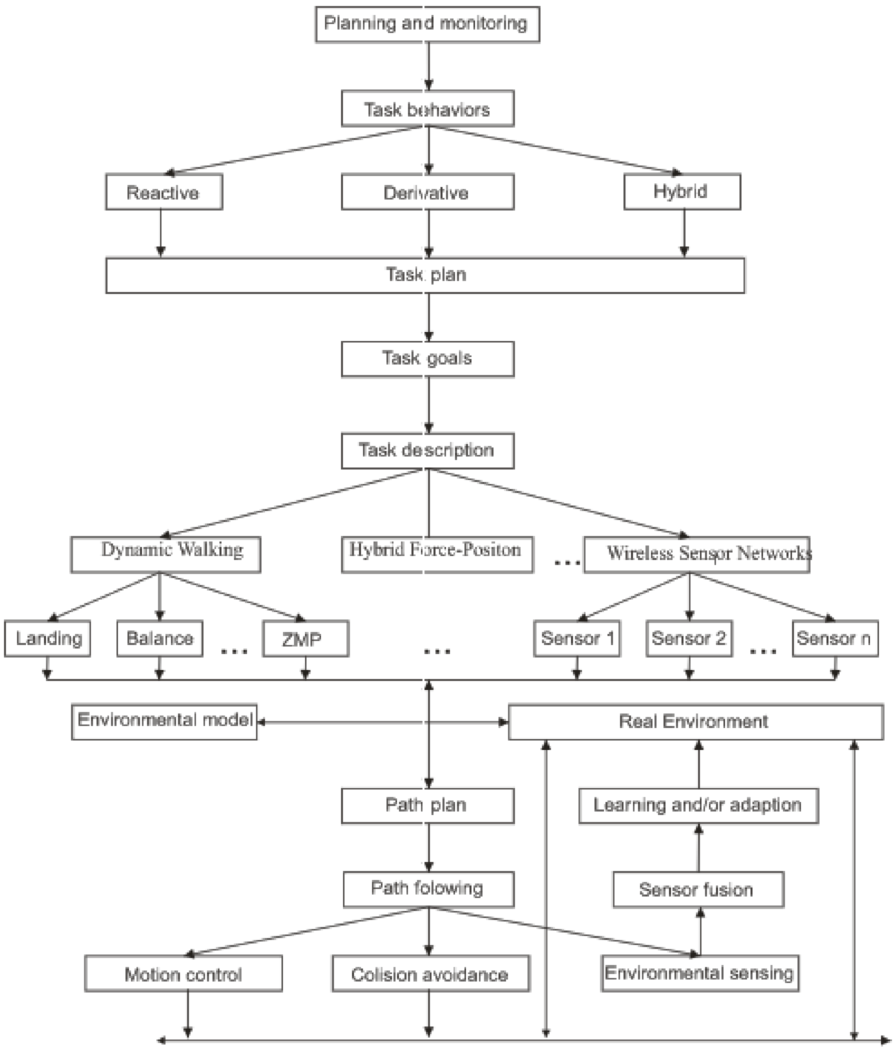

Figure 5.1. Control system architecture for a multi-sensor robot

Chapter 6

Intelligent Extended Control Systems for Autonomous Robots Equipped with Multi-Sensor Positioning Systems

6.4. Intelligent control of trajectory generation and tracking for a multi-sensor robot

The application presents the studies and research undertaken to develop a model for a three-revolute robotic leg which would operate as part of an autonomous mechatronics platform. The first step in designing such an important part of the walking robot, irrespective of the total number of robotic legs, is ensuring the reference tracking and control capabilities for each manipulator. The work reported herein is part of a larger support effort for the design and development of autonomous rescue robots in an international research project, which is based on the interdisciplinary cooperation of a number of different fields.

Neuro-fuzzy modelling attempts to mimic the behaviour of a given system for which arrays of input and output values are provided by creating a fuzzy inference system to produce similar results. The fuzzy inference system is then learned (i.e. its parameters are optimized) using an artificial neural network algorithm. This sometimes requires a lot of testing and, as will be discussed later on, can provide mixed results, but it is a very convenient tool for simulating systems whose mathematical formulae are unknown or very complex.

In controlling a robot leg, the reference position is given in coordinates in Cartesian space, so these need to be converted into angular coordinates which can be fed as reference to the joint actuators. This process of inverse kinematics can become rather involved mathematically for higher order manipulators systems. It must be also taken into account that, while direct kinematics provides a unique valid solution, this is not necessarily true of inverse kinematics. A valid solution may or may not exist, and it may not be unique. To overcome these issues, an adaptive neuro-fuzzy inference system is trained to simulate the results normally obtained through inverse kinematics. This approach does not require any mathematical knowledge of the system, save that the input data to the ANFIS is generated by running direct kinematics on the possible range of values of the joint angles. It then learns to reproduce similar angles for a given desired Cartesian position.

The 3D robot leg modelled through Robo Analyzer is a three revolute joint mechanism as seen in Figure 6.29. These are analogous to the hip, knee and ankle joints.

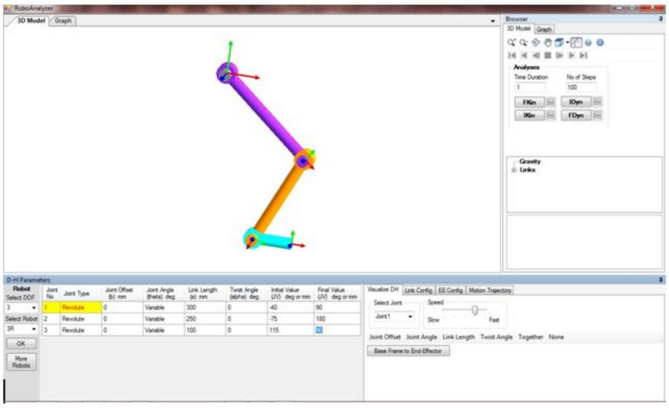

Figure 6.29. Robot leg model using Robo Analyzer

While the autonomous robot obviously works in a three-dimensional environment, each of the robot leg workspaces can be simplified to a two-dimensional space for simulation and design. It does, however, require at least three revolute joints due to considerations concerning the overall platform model, such as smooth landing and movement phase control. This also entails that the third angle (Θ_3) is to be controlled separately.

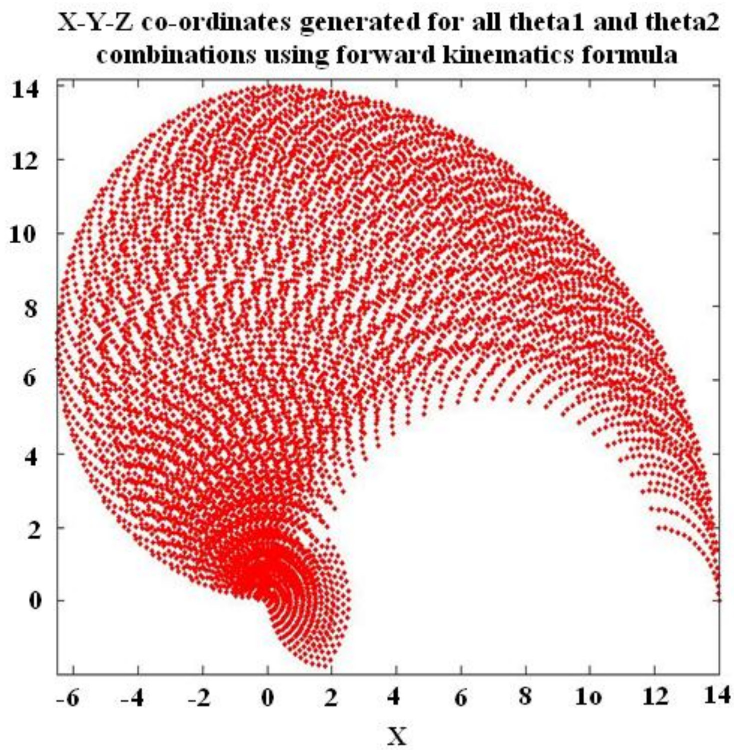

Figure 6.30. The robot workspace

An adaptive neuro-fuzzy inference system (ANFIS) is a modelling technique especially useful for systems where the mathematical laws that govern it are either very involved or altogether unknown. A fuzzy inference system (FIS) is built with the appropriate number of inputs and outputs for the given problem.

A neural network is then used to optimize the parameters of this FIS so as to obtain a minimum error in relation to the original input data. The position, shape and width of the membership functions and the inference rules are among the parameters being optimized by the neural algorithm. The operator must, however, specify a number of simulation parameters for the optimization, chief among them the number of membership functions per variable and the number of training epochs the algorithm is to run for. Special care must be taken not to over-fit the available data, which leads to the need for further testing once the algorithm has finished and to quite a bit of experimentation in regard to the values chosen for these simulation parameters.

One of the advantages of an ANFIS is that, for points in between the existing examples, it will approximate the result using a combination of rules fired by the closest inputs. Once it has been trained the resulting fuzzy inference system can be used in any simulation like a lookup table to replace the function of an inverse kinematics block.

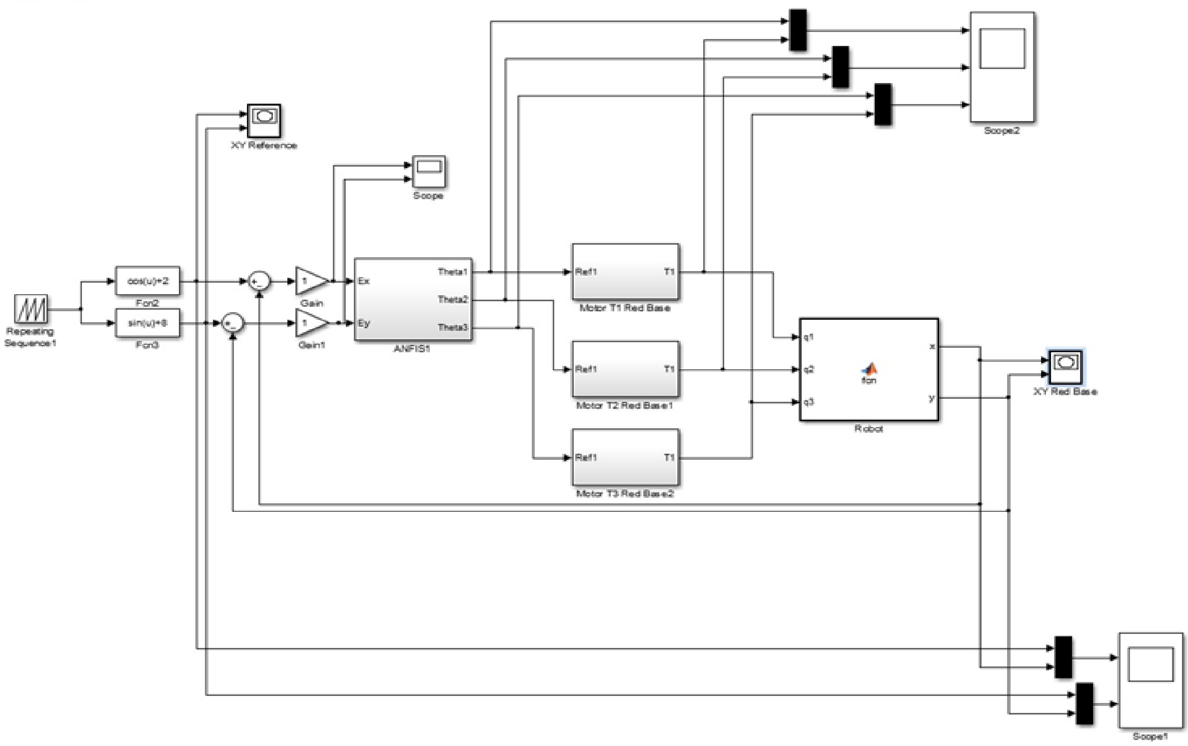

Figure 6.35. Architecture of the robot control system

The Enhanced Extenics controller uses the Dependent Function norm from Extenics Theory to determine the degree of compatibility of the system. It then makes the appropriate transformation in order to bring it into tracking compatibility. In practice this is achieved using a modified fuzzy controller that allows each of the respective compatibility ranges to be equated with fuzzy linguistic variables.

The reduced-base fuzzy logic controller is based on the observation that in most implementations of fuzzy logic control, the rules, inputs and outputs are symmetrical to the point of origin. The fuzzy inference space is then, in effect, doubled down on itself, which has been shown to produce similar results while significantly reducing FIS complexity [18]. There is a however band around the symmetry axis in which the sign of the error must be anticipated, otherwise it would lead to alternately positive and negative outputs of the same magnitude which could cause instability.

The chapter gives an overview of the studies and research undertaken to model a robotic leg for use on an autonomous multi-legged robot platform. The study shows that an adaptive neuro-fuzzy algorithm can be used to model the kinematics of a robot leg. Once the robot workspace is generated and the fuzzy inference system allowed to learn it using a neural network, it can be used to replace the inverse kinematics system and provide a nearly flawless reference conversion mechanism. The algorithm is not computationally expensive and gives satisfactory results even with a limited number of examples, as could be observed from the simulation itself.

The simulation model was then constructed using the ANFIS controller similarly to a lookup table to provide the necessary references to the angular actuator controllers. For this task, a selection of controllers was tested, all of which were previously optimized for a step input reference, using the same motors that are present in the simulation. This is in part responsible for the rather poor results shown by the PID controller as it favours the more robust fuzzy-based controllers.

The controllers were tested using a circular tracking reference for the overall system. The best results were achieved by the reduced-base fuzzy controller and, to a lesser extent, the enhanced Extenics controller. These will be further investigated as part of the larger model used for the autonomous platform

Chapter 7

Simulation Stand for Autonomous Robots Equipped with Multi-Sensor Systems

With the aim of validating the intelligent control laws for autonomous robots equipped with multi-sensor systems, experiments were undertaken on a simulation stand financed by the National Authority for Scientific Research within the research project „Essential and applicative research for the position control of HFPC MERO walking robots”, ID 005/2007-2010, in the program IDEI [31], which was developed for integration into the mobile rescue robot intelligent control platform VIPRO, project PCCA 2013 Parteneriate, ID 2009-2013, contract 014/2014 [111] in which the author is a member of the UPB research team.

The modular structure of the command and control system of the testing stand was conceived with the primary objective of data acquisition from the process sensors. To this end, through a serial network innate to the PLC AC500/CS31-ABB system, the commands are sent from the Master UC (central unit), which controls the PLC system, to the input-output modules of the slave programmable automates. These are intelligent modules equipped with micro-processors and provide an interface to the field elements, which are usually remote from the UC [146-148].

The control, monitoring and overseeing of technological processes is done by monitoring the technological flux and receiving confirmations for command executions, transducer status and the analogue measurements. For complex processes with multiple master central units, these will communicate through serial networks such as ModBus and Ethernet. The data exchange with the supervising PC system is generally done through Ethernet and for software development and human-machine interface Ethernet and RS232 are used [147].

The configuration module of a scalable system is presented in Figure 7.1. The CPU communication modules (the couplers) make communication possible between different units connected to the bus. The couplers are placed to the left of the CPU on the same base terminal support. The communication between the CPU and the couplers is done through the coupler interface, which is integrated into the base terminal [146].

Data interchange is done through a double-port RAM memory. Depending on the base terminal that is used, up to four couplers can function. There are no restrictions regarding the coupler order for the CPU or for the connection with the CPU internal coupler (Ethernet or Arcnet).

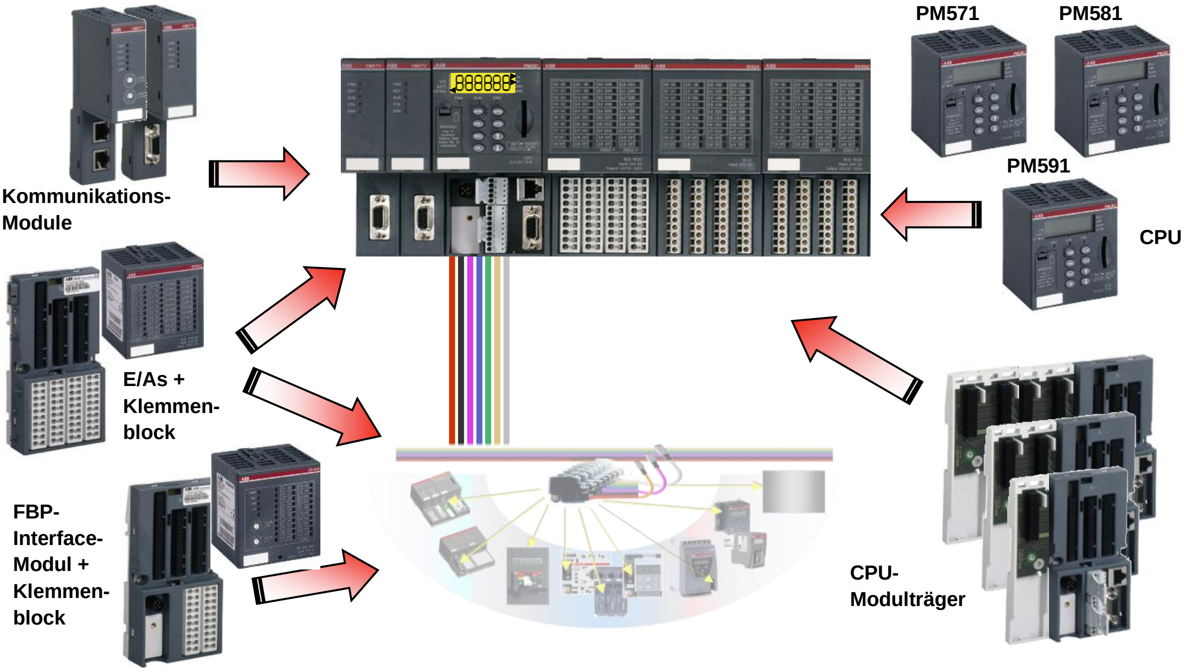

Figure 7.1. Configuration of a scalable PLC system using AC500

The system structure is composed of a central PLC unit allowing local control for each of the three degrees of freedom of the robot leg. The input-output modules allow data acquisition from the transducers and generate the reference signals of the motion trajectory to the actuators. The device sensors are used in two ways. In position control, the sensory information is used to compensate the robot joint deviation due to the load created by external forces, such that it accentuates the apparent rigidity of the robot joint system.

In force control, the joint is used similarly to a force sensor so that the robot is led in the same direction as the force received from sensors, allowing the desired contact force to be maintained.

Chapter 8

Conclusions and Contributions

8.1. Conclusions regarding the intelligent control for the autonomous motion of robots equipped with multi-sensor systems

Hybrid force-position control based on the eHPFC method using extenics and fuzzy logic is a high level control strategy which is well adaptable and scalable to the complexity of a humanoid mechatronic system. The hybrid force-position control strategy proposed brings numerous improvements to hybrid control of mobile walking robots, while extenics logic is in many regards superior to other laws for switching and selecting the control methods for each robot degree of freedom.

Extended equilibrium control of humanoid biped robots equipped with inertial sensors presents an innovative control method, necessary for autonomous robot navigation in unknown and unstructured environments. Using multidimensional extenics theory, it constitutes the main generalized algorithm of decisional navigation, based on the Șandru method for calculating multidimensional extenics norms.

Simultaneous localization and mapping modelled with Petri nets and Markov chains completes the operational aspect of those methods mentioned previously by conceiving a navigation and localization strategy and modelling the autonomous robot's tasks, which can be formally expressed through Petri techniques for decisional and transitional graphs.

There was conceived and developed a prototype of an optical orientation and navigation sensor with high precision and reduced cost, by processing the raw data initially acquired from an optical TOF laser sensor using an artificial neural network model.

There was studied and conceived a deep analysis of extenics theory with regards to solving contradictory problems, with applications in real time control of autonomous mobile robots and in optimizing robot performance by using multi-sensor systems. Extended actuator control presents successive improvement in relation to the usual control paradigm, leading to simplifying the conception and development tasks for complex mechatronic systems.

There is conceived, analysed and developed a new type of method for the

implementation of classical fuzzy inference systems, which allows reducing in half the complexity of a classical linear fuzzy inference system. With the aim of making the simulation as realistic as possible, all these methods are tested on a complex mechatronic manipulator, with a reference position generated by an adaptive neuro-fuzzy inference system (ANFIS).

The general conclusion of the research undertaken within the doctoral thesis is that the studies, analyses, strategies and control techniques presented, to which may be added the innovative solutions and original methods developed by the author contribute significantly to the research in the field of navigation and intelligent control of autonomous mobile robots equipped with multi-sensor systems in unknown and unstructured environments. Thus, the objective of this thesis is accomplished.

The obtained results allow future studies in the field of autonomous robot motion using multi-sensor systems in the presence of obstacles, as well as in fields such as artificial vision, intelligent auto-adaptive optimization algorithms, automation techniques and improvement of extended control.

8.2. Original contributions by the author:

The research undertaken in this doctoral thesis has led to the development and implementation of new solutions as regards the intelligent control of autonomous mobile robots equipped with multi-sensor systems, respectively:

1. ***I have made a detailed comparative study from which resulted the state of the art*** in current research and the proposed research field is validated as being one of major interest for universities and research centres the world over.
2. ***I have conceived, tested and implemented a new hybrid force-position control strategy based on real time eHFPC control*** by applying extenics to the optimal selection of the control laws for robot motion, which leads to increased movement and stability performance for autonomous mobile robots with multi-sensor systems on unknown and unstructured terrain.
3. ***I have conceived, tested and implemented a strategy for navigation in unknown and unstructured environments for an autonomous mobile robot***, based on Șandru multidimensional extenics norms and a type of evolutionary algorithm, which simplifies the navigation and obstacle avoidance tasks.
4. To this end, ***I have modelled the high level strategy for control and navigation of an autonomous multi-sensor robot*** using simultaneous localization and mapping (SLAM) elements, Petri Nets formalism and Markov probability chains.
5. ***I have conceived, tested and implemented a model for processing the raw information from an optical TOF laser sensor based on artificial neural networks***, following a detailed study of the various alternative methods for primary data processing, which has led to decreasing the scan time and improving sensor performance with a view to an implementation in a robotic application.

6. ***I have conceived an innovative model for using Smarandache n-dimensional extenics norms*** for the generation and quantization of the robot workspace for reference positions.
7. ***I have conceived, tested and implemented two types of innovative extended control***, applying the norms and principles of extenics theory to position actuator control for robots, thus demonstrating the practical validity of the concept and contribution to the emerging field of Extended Control.
8. ***I have conceived, tested and implemented a fuzzy inference system based on an innovative method*** for defining the inference space, which leads to reduced system complexity while maintain the performance standard.
9. ***I have conceived, tested and implemented a simulation model for a complex mechatronic system used in the development of autonomous mobile robots with multi-sensor systems*** for rescue operations, in which I have implemented and tested various control alternatives, using an adaptive neural networks application combined with fuzzy logic for generating the multidimensional reference position.

Based on the presented research, ***the author has developed, presented and published*** a total of 28 scientific papers in the thesis field. From the grand total, 12 have been published a first authors at prestigious national and international scientific events and specialist journals, 6 papers in ISI indexed journals, one with a 2.4 impact factor, 10 published papers indexed in ISI Proceedings, two papers published in BDI papers and 10 papers in BDI indexed international conferences.

The visibility of the author's research is proven by the joint cooperation for the publication of numerous papers with renowned authors at home and abroad, such as:

Prof. Hongnian Yu and Prof. Shuang Cang from Bournemouth University, UK,

Prof. Mingcong Deng from Tokyo University of Agriculture and Technology Japan,

Prof. Radu Ioan Munteanu and Prof. Cornel Brișan, from Universitatea Tehnică in Cluj-Napoca

Prof. Ovidiu I. Șandru, from Universitatea Politehnica București

Prof. Cai Wen and Prof. Yang Chunyan from Guangdong University, China,

Prof. Mircea Boșcoianu from Academia Forțelor Aeriene in Brașov,

Prof. Nikos Mastorakis from Hellenic Naval Academy and Executive Director of the World Scientific and Engineering Academy and Society,

Prof. Zengguang Hou and Prof. Xiao-Liang Xie from Chinese Academy of Science,

Prof. Chenkun Qi, Prof. Xianchao Zhao and Prof. Feng Gao from Jiao Tong University in Shanghai.

Prof. Luige Vlădăreanu, Prof. Veturia Chiroiu and Prof. Ligia Munteanu from Institutul de mecanica solidelor al Academiei Române, To this is added the close collaboration with Prof. Univ. Paul Şchiopu, validated by impact papers published in conferences and journals with high visibility, indexed ISI and BDI.

Many of said results have been brought to fruition through research contracts that the author has participated in and through the patents awarded to research teams I have been a part of.

The high scientific level of the undertaken research is accentuated through international collaborations within the European program FP7, IRSES, RABOT „Real-time adaptive networked control of rescue robots" with Bournemouth University, UK, as project coordinator, and partners: Staffordshire University, UK, Shanghai Jiao Tong University, China, Institute of Automation Chinese Academy of Sciences, China, Yanshan University, China, in which I have participated as a project member and had a 1 month secondment to Shanghai Jiao Tong University, one of the first hundred universities in the world and a 1 month secondment to the Institute of Automation of the Chinese Academy of Sciences, China.

It is also worth noting the participation in the research team for the project "Fundamental and applicative research for hybrid force-position control of modular walking robots in open architecture systems", within the fundamental research program PNII "Exploratory Research" – IDEI, ID 005/2007-2010, financed by the ANCS. Starting from this project, through my activity, I have also contributed to the development of the project proposal "Versatile, intelligent, portable, robot platform with adaptive network control for rescue robots", VIPRO, ID2009-2014-2016, financed by the UEFISCDI, which will allow me to further test and develop the control methods shown in the thesis.

The innovative characteristics of the thesis is evidenced by the many applications using extenics theory, founded by Prof. Cai Wen, which is of high current scientific significance through the use of extending common and fuzzy logic, introducing and using elements of uncertainty and contradiction which are paramount to modelling complex systems and advancing the field of artificial intelligence. It is worth noting that, together with Prof. Smarandache, from the University of New Mexico Gallup – USA and Prof. Vlădăreanu I was part of the first group of scientific researchers to undertake a research assignment at the University of Guangdong in September 2012 with the aim of fostering collaboration and extending the applications of extenics theory in the field of control and artificial intelligence.

The obtained results, superior to state of the art research published in well-known journals, ISI or BDI indexed, are relevant in the present thesis through the original concepts, validated by simulation and experiments, recognized at national and international level through the work published in international conferences in Harvard (USA), Tokyo (Japan), Chengdu, Shanghai, Beijing (China), Paris, Athens, Bucharest, in BDI and ISI indexed journals, as well as national and international prizes, gold medals awarded at the International Expositions in Zagreb 2008, Geneva 2008-2014, Moscow 2010, Bucharest 2010,2014, Warsaw 2009.

The publications, patents, international awards, gold medals and national and international research projects which I have contributed to during the doctoral thesis program, which ***validate the research results***, are presented as follows.

International awards, gold medals at national and international innovation expositions:

1. Luige Vlădăreanu, Cai Wen, Munteanu Radu Ioan, Yan Chunyan, **Vlădăreanu Victor**, Munteanu Radu Adrian, Li Weihua, Florentin Smarandache, Ionel Alexandru Gal, **Gold medal and Internațional Prize** of the 42st Internațional Exhibition of Inventions of Geneva 2014, 2-6 April 2014 "*Method and Device for Hybrid Force-Position extended control of robotic and mechatronic systems*", Patent OSIM A2012 1077/28.12.2012
2. **Luige Vlădăreanu**, Cai Wen, Munteanu Radu Ioan, Yan Chunyan, **Vlădăreanu Victor**, Munteanu Radu Adrian, Li Weihua, Florentin Smarandache, Ionel Alexandru Gal, **Internațional awarded** by the TECHNOPOL Scientific and Technology Association of the Russian Federation, The 42st Internațional Exhibition of Inventions of Geneva 2014, 2-6 April 2014 "*Method and Device for Hybrid Force-Position extended control of robotic and mechatronic systems*", Patent OSIM A2012 1077/28.12.2012
3. Ovidiu Ilie Șandru, Radu I. Munteanu, Luige Vlădareanu, Lucian M. Velea, Paul Şchiopu, Mihai S. Munteanu, Alexandra Șandru, Gabriela Tonț, **Victor Vlădareanu**, Ioan Bacalu, Lucian Stanciu, **Gold medal and internațional Prize of the 39th Internațional Exhibition of Inventions of Geneva 2011**, for the patent: *Method and device of propulsion without any source of self-energy for mobile systems*
4. Ovidiu Ilie Șandru, Radu I. Munteanu, Luige Vlădareanu, Lucian M. Velea, Paul Şchiopu, Mihai S. Munteanu, Alexandra Șandru, Gabriela Tonț, **Victor Vlădareanu**, Ioan Bacalu, Lucian Stanciu, I**nternațional award** awarded by Politechnica University of Hong Kong, **the 39th Internațional Exhibition of Inventions of Geneva 2011,** for the patent: *Method and device of propulsion without any source of self-energy for mobile systems*
5. Ovidiu Ilie Șandru, Radu I. Munteanu, Luige Vlădareanu, Lucian M. Velea, Paul Şchiopu, Mihai S. Munteanu, Alexandra Șandru, Gabriela Tonț, **Victor Vlădareanu**, Ioan Bacalu, Lucian Stanciu, **Gold Medal** of the 9th **a Internațional Exhibition of Inventions -ARCA 2011, Zagreb, CROAŢIA, 13-15 October 2011**, for the patent: Method and device of propulsion without any source of self-energy for mobile systems
6. O.I.Șandru, R.I.Muntean**u,** L.Vlădăreanu, L.M.Velea, P.Şchiopu, M.S.Munteanu, A.Șandru, G.Tonț, **V.Vlădăreanu**, I.Bacalu, L.Stanciu, **Gold Medal** of ROMANIAN Inventions at 5-th IWIS Exhibition, 3-5 November 2011, Warsaw, Poland, for the patent: *Method and device of propulsion without any source of self-energy for mobile systems*.

7. L.Vlădăreanu, L.M.Velea, R.A.Munteanu, T.Sireteanu, M.S.Munteanu, **V.Vlădăreanu**, C.Balas, G.Tont, O.D.Melinte, D.G.Tont, A.I.Gal, **Gold Medal** of the IV-th Internațional Warsaw Invention Show **IWIS 2010**, for the patent: *Method and Device for Walking Robot Dynamic Control*.
8. L.Vlădăreanu, L.M.Velea, R.A.Munteanu, T.Sireteanu, M.S.Munteanu, **V.Vlădăreanu**, C.Balas, G.Tont, O.D.Melinte, D.G.Tont, A.I.Gal, **Gold medal and internațional Prize of the 38th Internațional Exhibition of Inventions of Geneva 2010**, for the patent: *Method and Device for Walking Robot Dynamic Control*.
9. L.Vlădăreanu, L.M.Velea, R.A.Munteanu, T.Sireteanu, M.S.Munteanu, **V.Vlădăreanu**, C.Balas, G.Tont, O.D.Melinte, D.G.Tont, A.I.Gal, **Internațional Award and Diploma** of Internațional Warsaw Inventions Show **IWIS**, Association of Polish Inventors and Rational, in **the 38th Internațional Exhibition of Inventions of Geneva 2010**, for the patent: *Method and Device for Walking Robot Dynamic Control*.
10. L.Vlădăreanu, L.M.Velea, R.A.Munteanu, T.Sireteanu, M.S.Munteanu, **V.Vlădăreanu**, C.Balas, G.Tont, O.D.Melinte, D.G.Tont, A.I.Gal, **Medal and internațional Prize** of The X Moscow Internațional Salon Of Innovations and Investments, September 2010, Moscow, Russia, for the patent: *Method and Device for Walking Robot Dynamic Control*.
11. R.I.Munteanu, L.Vlădăreanu, O.Șandru, L.M.Velea, H.Yu, N.Mastorakis, G.Tont, E.Diaconescu, R.A.Munteanu, **V.Vlădăreanu**, A.Șandru, **Special Prize, in Recognition of Meritorious Achievements for the Innovative Invention**, Isfahan University of Technology, Robotic Center, Republic of Iran, in **The 38th Internațional Exhibition of Inventions of Geneva 2010**, for the patent: A00626/07.08.09: *Method and Device for Driving Mobil Inertial Robots*.
12. R.I.Munteanu, L.Vlădăreanu, O.Șandru, L.M.Velea, H.Yu, N.Mastorakis, G.Tont, E.Diaconescu, R.A.Munteanu, **V.Vlădăreanu**, A.Șandru, **Gold Medal with mention and Internațional Prize of the 38th Internațional Exhibition of Inventions of Geneva 2010**, for the patent: A00626/07.08.09: *Method and Device for Driving Mobil Inertial Robots*.
13. R.I.Munteanu, L.Vlădăreanu, O.Șandru, L.M.Velea, H.Yu, N.Mastorakis, G.Tont, E.Diaconescu, R.A.Munteanu, **V.Vlădăreanu**, A.Șandru, **Gold medal** of The X Moscow Internațional Salon Of Innovations And Investments, September 2010, Moscow, Russia, for the patent: *Method and Device for Driving Mobil Inertial Robots*.
14. O.I.Șandru, R.I.Munteanu**,** L.Vlădăreanu, L.M.Velea, P.Şchiopu, M.S.Munteanu, A.Șandru, G.Tonţ, **V.Vlădăreanu**, I.Bacalu, L.Stanciu,, I**nternațional award**ed by the **TECHNOPOL** Scientific and Technology Association of the Russian Federation, Moscow, in The Belgian Internațional Trade Fair for Technological Innovation, EUREKA, Bruxelles, November 2010, for the patent: *Method and device of propulsion without any source of self-energy*

for mobile systems.

15. R.I.Munteanu, L.Vlădăreanu, O.Șandru, L.M.Velea, H.Yu, N.Mastorakis, G.Tont, E.Diaconescu, R.A.Munteanu, **V.Vlădăreanu**, A.Șandru, **Gold Medal with Mention** of the IV-th Internațional Warsaw Invention Show **IWIS 2010**, for the patent: *Method and Device for Driving Mobil Inertial Robots*

OSIM and EPO Inventions:

1. ***„Method and device for dynamic control of a walking robot"*** Publication no.: **EP2384863,** App. No.: 10464006.5/EP10464006, PATENT: OSIM A/00052/21.01.2010, authors: LuigeVlădăreanu, Lucian Marius Velea, Radu Adrian Munteanu, Tudor Sireteanu, MihaiStelianMunteanu, Gabriela Tont, **Victor Vlădăreanu**, Cornel Balas, D.G. Tont, Octavian Melinte, Alexandru Gal
2. "***Method and Device for Hybrid Force-Position extended control of robotic and mechatronic systems***", PATENT: OSIM A2012 1077/28.12.2012, authors: LuigeVlădăreanu, Cai Wen, R.I.Munteanu, Yan Chuyan, **Victor Vlădăreanu,** Weihua Li, Radu Adrian Munteanu,FlorentinSmarandache,Alexandru Gal.
3. ***Real-time control method and control device for an actuator*** ,Vlădăreanu Luige, Velea Lucian Marius, Munteanu Radu Adrian, Munteanu Mihai Stelian, **Vlădăreanu Victor,** Velea Alida Lia Mariana, Moga Daniel , Publication no.: EP2077476,App no.: 08464013.5/EPO 08464013

National and international scientific research programs:

1. Member in FP7 project: "*Real-time adaptive networked control of rescue robots*", acronym RABOT, 2012-2015 of the 7th Framework Program for Research, Project Marie Curie, International Research Staff Exchange Scheme (IRSES), coordinator: Staffordshire University, UK , partners: Institute of Solid Mechanics of Romanian Academy, Bournemouth University, UK, Shanghai Jiao Tong University, CN, Institute of Automation Chinese Academy of Sciences, CN, Yanshan University
2. Member in national project: PNII PT PCCA 2013 4 ID2009, "*Versatile Intelligent Portable Robot Platform using Adaptive Networked Control Systems of Rescue Robots*", Coordinator – Institute of Solid Mechanics of Romanian Academy
3. Member in national project: PNII PT PCCA 2011-2014-3.1-0190, Contract 190/2012"*Reconfigurable haptic interfaces for the modelling of dynamic contact*" "*Interfete haptice reconfigurabile utilizate in reproducerea contactului dinamic*",Coordonator – Institute of Solid Mechanics of Romanian Academy
4. Member in research team of: "*Essential and Applied Research for HFPC MERO Walking Robot Position Control*", ID 005/2007-2010,IDEAS Program, coordinator NCSR, financed by National Authority for Scientific Research.
5. Member in research team of: "Real time modular and configurable automation system for decentralized systems" Project, ID 11/2007-2010, IDEAS Program, coordinator NCSR, financed by National Authority for Scientific Research
6. Member in research team of: "Real time modular and configurable automation system for distributed systems", ID 127/2007-2010, IDEAS Program, coordinator

NCSR, financed by National Authority for Scientific Research.

7. Participated in the applicative research project: „Electrical Motors Test Bench", beneficiary Universitatea Tehnică Cluj-Napoca.

8. Member in research team of: "Hydrostatic servo-actuator for planes", Acronym SAHA, Contract no. 81-036 / 18.09.2007-2010, Partnership Program, coordinator CNMP, financed by National Authority for Scientific Research.

8.3. List of original papers

Scientific papers in ISI indexed journals:

1. **Vlădăreanu V**. , Șandru I., Sensors Fusion for Modelling and Wear Control of Artificial Joint, accepted for publication in J. of Biomechanics, S077, Elsevier, ISSN 0021-9290, ISI Indexed, Impact Factor 2.4

2. Șandru, O.I., Vlădareanu, L., Șchiopu, P., **Vlădareanu, V.,** Șandru, A., Multidimensional extenics theory, UPB Scientific Bulletin 2013, Series A: Applied Mathematics andPhysics, 75 (1), pp. 3-12, ISSN 1223-702

3. Vlădăreanu L., **Vlădăreanu V.**, Șchiopu P., „Hybrid Force-Position Dynamic Control of the Robots Using Fuzzy Applications", 3-rd Edition of the IEEE/IACSIT Internațional conference on Biomechanics, Neurorehabilitation, Mechanical Engineering, Manufacturing Systems, Roboțics and Aerospace, ICMERA2012, Bucharest, 26-28 October 2012, pp.8, Invited Paper

4. Munteanu L., BrisanC., DumitriuD., VasiuR.V., ChiroiuV., MelinteO., **Vlădăreanu V**., On the modeling of the tire/road dynamic contact, Transportation Research part C: Emerging Technologies 2013 ISSN 0968-090X

5. DumitriuD., MunteanuL., BrisanC., ChiroiuV., VasiuR.V., MelinteO., **Vlădăreanu V**., On the contionuum modeling of the tire/ road dynamic contact, CMC: Computers, Materials & Continua, 2013, IF 0,972 ISSN 1546-2218.

6. **VlădăreanuV**. , Șchiopu P., Vlădăreanu L., Theory And Application Of Extension Hybrid Force-Position Control In Roboțics, U.P.B. Sci. Bull., Series A, Vol. 75, Iss.2, 2013, ISSN 1223-702

Scientific papers in BDI indexed journals:

7. **Vlădăreanu V.**, Tonț G., Vlădăreanu L., Smarandache F., The Navigation of Mobile Robots in Non-Stationary and Non-Structured Environments, Int. Journal of Advance Mechatronic Systems Internațional Journal of Advanced Mechatronic Systems 01/2013; 5(4):232- 243. DOI: 10.1504/IJAMECHS.2013.057663, ISSN online: 1756-8420, ISSN print: 1756-8412, Excellence in Research for Australia (ERA): Journal list 2012 , Scopus (Elsevier)

8. Vasiu R.V., MelinteO., **Vlădăreanu V**., DumitriuD., On the response of the car from road disturbances, Revue Roumaine des Sciences Techniqués – Série de MécaniqueAppliquée, nr.3, 2013 ISSN: 0035-4074

International scientific papers indexed ISI

9. **Vlădăreanu V.**, Schiopu P., Cang S and Yu H, "Reduced Base Fuzzy Logic Controller for Robot Actuators", Applied Mechanics and Materials Vol. 555 (2014) pp 249-258© (2014) Trans Tech Publications, Switzerland doi:10.4028/www.scientific.net/AMM.555.249, indexata ISI

10. **Vlădăreanu V.**, Schiopu P, Deng M., Yu H., " Intelligent Extended Control of the Walking Robot Motion" Proceedings of the 2014 Internațional Conference on Advanced Mechatronic Systems, Kumamoto, Japan, August10-12, 2014, pg. 489-495, ISBN 978-1-4799-6380-5, 2014 IEEE, ISI Proceedings

11. **Vlădăreanu V**., Smarandache F., Vlădăreanu L., Extension Hybrid Force-Position Robot Control in Higher Dimensions, Internațional Conference Optimisation of the Robots and Manipulators Applied Mechanics and Materials Vol. 332 (2013) pp 260-269, (2013) Trans Tech Publications, Switzerland, doi:10.4028/www.scientific.net/AMM.332.260

12. Vlădăreanu L., Șandru O.I.,**Vlădăreanu V**., The Robot Real Time Control using the Extenics Multidimensional Theory, Recent Advances in Roboțics, Aeronautical and Mechanical Engineering (MREN), Athens 2013

13. **Vlădăreanu V**., Tonț G., Şchiopu P., Bayesian Approach of Simultaneous Localization and Mapping (SLAM) in a Wireless Sensor Networks Navigation for Mobile Robots in Non- Stationary Environments, Recent Advances in Roboțics, Aeronautical and Mechanical Engineering (MREN), Athens 2013

14. Tonț G., **Vlădăreanu V.**, Risk-Based Approach in Availability Management for Dynamical Complex Systems, Recent Advances in Roboțics, Aeronautical and Mechanical Engineering (MRME), Dubrovnik 2013

15. Vlădăreanu L., Șchiopu P., **Vlădăreanu V**., Extenics Theory Applied to Roboțics, Mathematical Applications in Science and Mechanics (MATHMECH), Dubrovnik 2013

16. Vlădăreanu L., **Vlădăreanu V**., Şchiopu P. , Hybrid Force-Position Dynamic Control of the Robots Using Fuzzy Applications, ICMERA,Applied Mechanics and Materials Vol. 245 (2013) pp 15-23 (2013) Trans Tech Publications, Switzerland ISBN 978-3-03785-554-6

17. **Vlădăreanu V.**, Schiopu P., Șandru O.I. and Vlădăreanu L., "Advanced Intelligent Control Methods in Open Architecture Systems for Cooperative Works on 4 Nano-Micro-Manipulators Platform", ISI Proceedings

18. **Vlădăreanu V.**, Schiopu P., Cang S, Yu H, Deng M., "Enhanced Extenics Controller for Real Time Control of Rescue Robot Actuators", UKACC 10th Internațional Conference on Control (CONTROL 2014), Loughborough, U.K., 9th - 11th July 2014, acceptata spre publicare la IFAC (Internațional Federation of Automatic Control), ISI Proceedings

International scientific papers indexed BDI

19. **Vlădăreanu V.**, Deng M., Schiopu P., "Robots Extension Control using Fuzzy Smoothing", Proceedings of the 2013 Internațional Conference on Advanced Mechatronic Systems, Luoyang, China, September 25-27, 2013, pg. 511-516, ISBN 978-0-9555293-9-9, IEEE indexed
20. Șandru O.I., Vlădăreanu L., Șandru A., **Vlădăreanu V**., Stanciu C.L., Stamin C., Serbanescu C., Genetic Algorithm For Learning Automata, SISOM 2013, Session of the Commission of Acoustics, Bucharest 21-22 May 2013
21. Dumitriu D., MelinteO., **Vlădăreanu V**., Simularea interactiunii verticale dintre autovehicul and drum folosind CARSIM, A 37-a Conferinţă Națională de Mecanica Solidelor, Acustică and Vibraţii CNMSAV XXXVII Chişinău, MD-2070,Republica Moldova, 6-8 Iunie 2013
22. Dumitriu D., Melinte D., **Vlădăreanu V**., Half-Car Vertical Dynamics Using Carsim Software, Advanced Engineering In Mechanical Systems (ADEMS 2013)
23. **Vlădăreanu, V**, Moga R, Schiopu P, Vlădăreanu L "Multi-Sensors Systems Using Semi-Active Control forMonitoring and Diagnoses of the Power Systems", 2nd IFAC Workshop on Convergence of Information Technologies and Control Methods with Power Systems, 2013, Volume # 2 | Part# 1, IFAC, Elsevier, Digital ObjectIdentifier (DOI), 10.3182/20130522-3-RO-4035.00044, pg.78-83, ISBN: 978-3-902823-32-8,
24. **Vlădăreanu V.**, ȘandruO., Şchiopu P., Șandru A., Vlădăreanu L., Extension Hybrid Force-Position Control of Mechatronics Systems, First Internațional Symposium of Extenics, Beijing 2013
25. ȘandruO., Vlădăreanu L., Șchiopu P., **Vlădăreanu V.**, Șandru A., New Progress In Extenics Theory, First Internațional Symposium of Extenics, Beijing 2013
26. ȘandruO., Vlădareanu L., Șchiopu P., Toma A., Șandru A., **Vlădăreanu V**., Stanciu L., Extenics Model for Equilibrium Control of Bipedal Robots, First Internațional Symposium of Extenics, Beijing 2013
27. Șandru O.I., Vlădăreanu L., Schiopu P., Șandru A., **Vlădăreanu V.**, "Applications of theExtensionTheory in Machine Learning Field", Proceedings of the 2013 Internațional Conference on Advanced Mechatronic Systems, Luoyang, China, September 25-27, 2013, pg. 524-529, ISBN 978-0-9555293-9-9, IEEE indexed
28. Vlădăreanu, L., Tont, G., **Vlădăreanu, V.**, Smarandache, F., Capitanu, L., The Navigation Mobile Robot Systems Using Bayesian Approach Through The Virtual Projection Method, The 2012 Internațional Conference on Advanced Mechatronic Systems, pp. 498-503, 6pg.ISSN: 1756-8412, 978-1-4673-1962-1, INSPEC Accession Number: 13072112, 18-21 Sept. 2012, Tokyo

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