IOSUD - Universitatea Politehnica Timişoara
Şcoala Doctorală de Studii Inginereşti

ANALYSIS AND SYNTHESIS OF MOBILE ROBOTIC SYSTEMS

Teză de doctorat – Rezumat

pentru obținerea titlului științific de doctor la
Universitatea Politehnica Timişoara
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The research activities outlined in the research plan were conducted within the Sensors and Actuators Laboratory of the Mechatronics Department at the Politehnica University of Timişoara. These activities were part of the research project carried out by the Politehnica University of Timişoara: "Increasing the Attractiveness and Performance of Doctoral and Postdoctoral Training Programs for Researchers in Engineering Sciences - ATRACTING," under the major intervention area: "Doctoral and Postdoctoral Programs in Support of Research," and the priority axis: "Education and Vocational Training in Support of Economic Growth and Knowledge-Based Development."

One focus was on sensory elements useful in constructing mobile robots, aiming to obtain real information from the working environment. The second focus was on developing a structure for a mobile robot and its theoretical and experimental analysis.

The first part of the doctoral thesis begins with a literature review related to the mechatronics of mobile robots, analyzing their functions. The important functions of a mobile robot are: the driving function, the control function, and the perception function of the environment in which it operates. Thanks to these functions, the mobile robot interacts with its environment through reciprocal actions.

One of the important aspects in the sensory field is determining the actual distances from objects in the working environment of mobile robots, using a highly advanced sensory system through which the robot can make quick decisions to correct its trajectory and type of action.

The results of the research carried out for the doctoral thesis were disseminated through the publication of eight papers at national and international conferences and in specialized journals.

The research conducted to achieve the main objective and secondary objectives of the thesis is succinctly described in the chapters of the doctoral thesis.

In Chapter 1 – *Introduction* – the field and research directions of the present doctoral thesis are specified, the importance and relevance of the research in the broader field of mechatronics are justified, [M11][V3][206] the general context of mobile robotics is presented, [L2][L3][M9][S4][S12] the motivation of the topic is highlighted, and the main objective of the thesis is formulated. The structure and organization of the thesis are described through a block diagram that outlines the activities undertaken for the thesis development and how they relate to the operational objectives. At the end of the chapter, the structure of the doctoral thesis across the six chapters and their extensions is presented. Chapter 1 contains 8 pages and includes 4 figures and 1 appendix.

In Chapter 2 – *The Current State in Mobile Robotics* – a bibliographic synthesis regarding the introduction to mobile robotics [D12] is presented, inspired by biomechanics [V4]. The chapter refers to the specific characteristics of mobile robotics: definition, evolution, and classification criteria [B10]. Regarding the general aspects of mobile robotic system architecture, the three basic subsystems are presented: the sensory subsystem, the actuation subsystem, and the control and command subsystem. [D11][G8]. Finally, some existing algorithms for controlling mobile robots are reviewed and analyzed, presenting their advantages and limitations [D16][N9]. This chapter also analyzes and synthesizes the kinematic calculations of the transmissions integrated into the actuation subsystem[L6][P4][M12]. These are transformed into mathematical models obtained based on the physical laws related to mechanical and electrical aspects [A3][A5].. The chapter concludes with future trends concerning actuators and applications in mobile robotics. The conclusions at the end of the chapter emphasize the need to achieve the specified objectives, namely optimizing the component systems, including sensory ones. Chapter 2 contains 24 pages and includes 37 figures, 6 tables, 10 calculations, and 7 appendices.

In Chapter 3 – *Studies on the Operating Principles of Sensory Elements* – experimental setups are presented regarding the working procedures and statistical data analyses used for the optimal selection of sensory elements. Experiments were conducted using three sensors frequently used in mobile robotic systems: ultrasonic sensors, infrared sensors, and optical sensors. Each type of sensor has advantages and limitations that affect optimal functioning, so their selection is based on application requirements. It is considered that using data fusion techniques can improve the precision and reliability of robotic systems. Combining information from different sensors can provide a more complete and accurate picture of the environment. The chapter includes examples of interpreting probabilistic distributions in robotics, handling multiple variables, and calculating an estimated value based on sensor information. Each experiment was accompanied by the calculation for probability density and its graphical expression. The final conclusions of this chapter refer to the necessity of optimal sensor selection following evaluation and comparison based on multiple criteria simultaneously, using weighting techniques. Chapter 3 contains 69 pages and includes 86 figures, 47 tables, 47 calculations, and 19 appendices.

In Chapter 4 – *Study of the Behavior of Sensory Elements in Mobile Robotic Systems* – the actuation systems for four different robots were analyzed and synthesized based on information received from sensors in experimental areas. A four-wheeled mobile robot is equipped with two ultrasonic sensors. The humanoid robot is equipped with three sensors: gyroscopic, infrared, and ultrasonic. The mobile humanoid robot is equipped with a gyroscopic sensor developed on LEGO NXT 2 educational kits. A drone whose control uses a smart glove equipped with an accelerometer sensor. The chapter includes theoretical and practical considerations regarding mobile robot navigation. Mathematical models attributed to robots are used to implement motion control software on dedicated hardware platforms. The robot structures are available in the Sensors and Actuators Laboratory of the Mechatronics Department at the Politehnica University of Timişoara. Concrete examples, simulations, and conclusions are presented. At the end of the chapter, experimental results are inserted, obtained by monitoring the behavior of the robots in the working scene. One of the final conclusions refers to the combined use of sensors. By strategically placing them to maximize coverage and minimize dead angles, optimal perception of the surrounding environment is enabled. Chapter 4 contains 31 pages and includes 37 figures, 9 tables, 33 calculations, and 9 appendices.

Chapter 5 – *Research on Applications of Mechatronic Platforms in Education* – has the operational objective of using mechatronic platforms in educational projects. This chapter addresses representative models of educational platforms: Arduino, Lego Mindstorm NXT, Festo, and Omron. The study of the proposed topics within these platforms is carried out using

physical and virtual platforms [D11]. Throughout this chapter, it is considered that the experimental results obtained in previous chapters form the basis of the applications used. Simulation allows for testing the correctness of the project before practical implementation. The creation of web pages and their advantages are presented at the end of the chapter. In conclusion, the use of mechatronic platforms in educational projects encourages creativity and innovation. Chapter 5 contains 30 pages and includes 42 figures, 7 tables, and 2 appendices.

Chapter 6 – *Final Conclusions, Contributions, and Future Recommendations* – is a synthesis of the activities carried out, the conclusions drawn from the activities, and a review of personal contributions and recommendations for future research. Chapter 6 contains 5 pages. The bibliography includes some of the titles used during the thesis development. The bibliography comprises 286 titles over 14 pages.

The Appendices chapter includes materials generated and processed during the thesis development. These materials were used for drafting the thesis chapters.