Universitatea *Transilvania* din Braşov

HABILITATION THESIS

SUMMARY

SERVOSYSTEMS FOR MOTION CONTROL IN THE ROBOTS' TECHNIQUE

Domain: Electrical engineering

Author: Prof. dr. eng. Aurel Fratu

University Transilvania of Brasov

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Summary

Within the framework of the current habilitation thesis, my scientific, professional and academic achievements are summarized over a period starting with 1994 (the date when my PhD thesis was defended, then certified by Minister's Order 6082/21.04.1994) until present (2014). Some of my national and international research grants, important papers, books, patents, teaching activities/materials are also detailed in the context of the actual stage of the scientific domain of electrical engineering with emphasis on the innovative aspects and personal contributions.

The first part (A) of the thesis is constituted by the present abstract (both English and Romanian versions).

The second part (B) of the current thesis refers to the scientific and professional achievements and the evolution and development plans for career development and is comprise three sections (B-i), (B-ii) and (B-iii).

Section (B-i) comprises an introduction and four chapters witch present four main research topics, prefaced by an introduction.

In introduction one present an overview of activity of the author of the habilitation thesis, referring to the most prominent research topics - classified in four principals themes-professional and academic achievements, newly introduced disciplines, taught courses, contribution to the development of the academic curricula, invited professor, students internship, conducting diploma and dissertation theses, international cooperation, management activities, etc.). The most important mentioned aspects are: a number of 73 research articles published in the above mentioned period, 4 research grants (2 as grant/contract director) and 8 books.

In chapter 1 is presented the following theme:

- **Dynamic models for control system design of integrated robot and drive systems**

The main problem of motion robot control is to generate the motion in the task space with a given command at drive systems level. This can be achieved by different strategies. The more natural strategy consists of inverting the kinematics of the manipulator to compute the joint motion corresponding to the given end-effectors motion.

Current systematic approach to design controllers for nonlinear systems is feedback linearization. The basic idea of this technique is to design a control law that cancels the nonlinearities of the system and yields a closed-loop system with linear dynamics.

In the first subchapter of chapter 1 a universal equation of motion for robotic systems with non-ideal constraints is obtained. Here, the nonlinear systems control problem is analysed with no assumption on the type of controller that is to be used. The results provided in this paper yield new and explicit method for the control of highly nonlinear systems.

Second subchapter of chapter 1 concerns mechatronic system design for the feed-forward control of high-speed motion. In the integrated robot and drive systems the main specifically properties, in the speed motion control, are the complexity of the dynamics and uncertainties, both parametric and dynamic. Parametric uncertainties arise from imprecise knowledge of kinematics parameters and inertia parameters, while dynamic uncertainties arise from joint and link flexibility, actuator dynamics, friction, sensor noise and unknown environment dynamics.

The proposed approach includes the design of drive system and the motion control. The goal is to design both mechanical transmission and electrical motor in order to achieve the performance specifications with the controller. The inverse elasto-dynamic model of the system is used for control and to establish the design constraints due to physical limits. The design problem is then represented in the form of the Pareto frontier which allows an optimal choice of the motor as well as an optimal sizing of the transmission mechanism. An example shows that this design approach leads to obtain the performance specified. Moreover, the performances of the integrated robot system are robust to modelling and identification errors.

In chapter 2 is presented the following theme:

- **Haptic interfaces**.

The first subchapter of chapter 2 addresses the stability issue of haptic interface in contact with a virtual wall. This paper presents an overview on the methodology and the stable region affected by some parameters: physical damping, time delay, human dynamic characteristics.
The goal of this paper is to analyze the influence of the dynamic parameters on the stability boundaries. This study shows how the factors such as physical damping coefficient, time delay and human operator parameters affect the stability of a haptic system. The influence of vibration type on the stability is also studied in this paper. The results are carried out on the physical parameters of a PHANTOM®.

In the second subchapter of chapter 2 of this section a method for displaying tactile sensation of cutting, using a virtual scissors type, is described. A new algorithm to be used in general interactive manipulations of deformable objects is presented. The algorithm was developed to simultaneously display translational and rotational (cutting) displacement for a realistic cutting simulation. We showed that interactive animations can be used to simulate the functioning of force/torque - feedback scissors devices. This paper confers the experience with the design process in the virtual environment and ones determine the novel features for the possible torque-feedback scissors-robot devices.

In chapter 3 is presented the following theme:

- **The reciprocal robots collision avoidance**.

The aim of the first subchapter of chapter 3 is to analysis the problem of redundant inverse kinematics and obstacles avoid subtask are defined, for exploiting the self motion.

The strategy proposed allows the use of redundant degrees of freedom such that a manipulator can avoid obstacles, while tracking the desired end-effectors trajectory. It is supposed that the obstacles in the workspace of the manipulator are static. This strategy is applied also when the configuration of the manipulator can be influenced by further requirements such as joint limits, etc.

The effectiveness of the proposed strategy is discussed by theoretical considerations and illustrated by simulation of the motion of the four-joint planar manipulators between symmetric obstacles. It is shown that the proposed collision avoidance strategy while tracking the end-effector trajectory is efficient and practical.

The second subchapter of chapter 3 detailed work develops a original method for collision avoid, based on the motion imitation concept. Motion imitation requires a demonstrator and an imitator. In our approach the demonstrator is the virtual robot prototype and the imitator is the physical real robot. The inputs of the imitation procedure are virtual joint trajectories represented such a sequence of angular values of its joints. The imitator imitates the original motion captured from virtual prototype, and at the same time this respects the physical constraints.

The strong point of the proposed method is that it provides on-line re-planning of the motion in the face of spatial-temporal perturbations (obstacles) based on particular scenarios. The virtual robot motion must cover all possible contexts - including the presence of accidental obstacles - for which the physical robot will need to generate similar motions.

The collisions avoid method, based on the imitation of virtual prototypes, must be still enhanced to respond at the question: how dynamical virtual system models one can be up-dated online to take dynamic events, from the real environment, into account? The author expect fully automated robot programming by imitation, using robust enough system to be applied in practical applications, will not become true before the end of this decade.

In chapter 4 is presented the following theme:

- **Modelling and robots' behavioural simulation in visual environments.**

The aim of the first subchapter of chapter 4 is to evaluate the problem of virtual prototyping. Virtual prototyping provides a means to qualitatively describe product behavior from various aspects.

Virtual prototyping is a software-based engineering discipline which involves modelling a system, simulating and visualising its behaviour under real-world operating conditions, and refining its design through an iterative process. The full-motion behaviour of complex robotic systems can be analysed before building an actual hardware prototype. Users can quickly explore multiple design variations, testing and refining until system performance is optimised. This can help reduce the time and cost of new product development.

The purpose of second subchapter of chapter 4 is to emphasize the role of the simulation in different fields of robotics. Being able to simulate, opens a wide range of options for solving many problems creatively. We can investigate, design, visualize and test a robot arm even if it does not exist. We can see the performances of a system before it is built. It is possible that our solutions may fail or even blow up, but only in simulating on the virtual prototype.

Simulation has been recognized as an important tool in robotics in designing new robots, investigating their performances and in designing applications of these robots. Simulation allows studying the structure's characteristics and the functions of robot systems at different levels of details, each posturing different requirements for the simulation tools. For example a fast process, as the moving robot joint, can be slowed down to observe all details in "slow motion".
As the complexity of the system under investigation increases, the role of the simulation becomes more and more important and using the simulation tools can certainly enhance the design development.

This approach discusses the using of the visual programming Delphi environment, for facilitating modeling and behavioral simulation of serial and parallel robotic arms.
The simulations prepared for this application were also made for the development of the systematic methods for creating the new robotic systems.
The results of this investigation consist in an identification of the properties and constraints that can appear in the case of the physical homonyms prototypes.

The virtual structures created in this paper encompass the applications with serial robot (illustration for the baggage sorting stations) and parallel robotic arms (illustration for a hexapod platform.

It is merit noticing that the main results achieved in *Dynamic models for control system design of integrated robot and drive systems* field are identified in the Section (B-iii) by the existence of *robot control* words in the title of the 19 article signed by the author of habilitation thesis.
The second research direction, namely *Haptic interfaces* has been treated in 5 publications (referred by the existence of *haptic* word in the title in Section (B-iii).

The third problematic, *The reciprocal robots collision avoidance* has been investigated in a number of 8 papers signed by the author of habilitation thesis (see references with the existence of *collision avoidance* words in the title in the Section (B-iii).

The results regarding the last research direction, *Modeling and robots behavioral simulation in visual environments*, were published by the author of habilitation thesis in 6 scientific publications (see references with the existence of *modeling and simulation* words in the title, in Section (B-iii).

Section (B-ii) presents my ***evolution and development plans for career development*** along with possible implementation means.

Here, for future the research of new communication strategies - between virtual and physical environment - are intended to be in depth studied (with applications for haptic interfaces and reciprocal collision avoidance). New implementation solutions are to be proposed (e.g. programming by imitation platform based on original patented idea). Also I intend to investigate new research fields in co-operation with researchers from University of Valenciennes and University of Reims - from France.

The third section (B-iii) is dedicated to the references.