UNIVERSITY OF CRAIOVA

FACULTY OF AUTOMATION, COMPUTERS AND ELECTRONICS

ABSTRACT
Ph.D THESIS

3D CONTROL SYSTEM FOR A HYPER-REDUNDANT ROBOT

Advisor: PhD. Prof. Eng. Mircea IVĂNESCU

Ph.D Candidate: ing. Alice PREDESCU

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Objectives

Hyper-redundant robots form a new class of robots which has raised the interest of a great number of scientists. Compared to classical structures which are designed with a reduced number of joints, serially connected with rigid structural elements and which operate in an unrestricted open operating space, the hyper-redundant robots are designed with a very high number of joints for high maneuverability in externally restricted operation spaces. These robotic models are user in various applications like locomotion on rugged terrain, searching and rescue operations, inspection of narrow places, or medical investigations.

The objective of this thesis is to analyze the main hyper-redundant robots control methods, to find the mathematical model of a hyper-redundant system and to implement a tele-operation system which can remotely control a robotic system.

Thesis Organization

The thesis is organized in five chapters, one conclusion chapter, one appendix and the bibliography.

Chapter 1 – *Hyper-redundant Robots – Fundamentals* - presents the main characteristics of hyper-redundant robots, underlying the main differences against the classical robots, followed by the presentation of some reference models described in the

literature. Then, a classification of hyper-redundant robots is presented, from the morphological and construction perspectives. The main actuator systems are described (pneumatic, hydraulic, intelligent material based - SMA, ER liquids, polymer artificial muscles), considering that a traditional electrical actuation is not feasible due weight of the mechanical support.

Chapter 2 – *Mathematical models of hyper-redundant robots* has a strong theoretical approach, through the synthesizing of the mathematical models of the most important hyper-redundant robotic structures and through the brief presentation of representative work studied by the author. This chapter represents a theoretical ground used by the next chapters of the thesis. Mathematical modeling of this type of robots targets both kinematics and dynamics. This chapter describes algorithms which allow the implementation of conventional PD controllers without using the complicated mathematical model of the mechanical arm. A fuzzy logic control system is then presented, and two distinct cases are analyzed: the case of stationary reference position the reference position of the robotic arm and the second case in which the reference position is time variant. Further, the differential kinematic control is analyzed. The differential model of the robot provides the relationship between the velocity of the operational coordinates and the velocity of the generalized coordinates, given by a Jacobian matrix. The robotic arm's Jacobian is one of the most important tools used by the conventional control theory. In the last part of this chapter a cooperative control system is described, which solves the problem of cooperation between two or more robots for executing a common task. Besides the complex problems involved by the movement of each arm, some specific problems must be solved, mostly related to the forces that must be applied on the target object in order to move it according to the task specifications.

Within **Chapter 3 –** *Video based control of hyper-redundant robot* – there are analyzed alternative hyper-redundant robots control system based on video cameras. Image based control systems – or visual servoing as referenced in literature – are classified, based on the error function given as the input of the control low, in four categories, which are briefly presented, along with the presentation of advantages and drawbacks of each of them. An important focus is given to the servo-control based on the visual information extracted from images, as it provides a much faster and simpler solution that reduces the computing delays and eliminates the need of image interpretation and the camera calibration errors. This approach has been demonstrated with two applications: one application that uses a fixed external camera and one application that uses two external cameras. For a better control of a hyper-redundant robot the possibility of avoiding joints' limits and kinematic singularities is analyzed, due to the fact that in the case when the control law outputs movement beyond the robot's limits, the given task cannot be executed. The last part of the chapter presents a control method of hyper-redundant manipulator based on mobile cameras, the robot being composed of a robotic trunk mounted on a mobile base. This robot is used in search and rescue operations.

Chapter 4 –*Hyper-redundant tronconic robot – experimental platform* – presents the mathematical model of a hyper-redundant arm developed within the Mechatronics Department of the Faculty of Automation, Computers and Electronics, University of Craiova. This robotic system is described from the mechanical perspective and the control and actuation systems are presented. In order to facilitate the kinematic model and robot functional test, a Matlab simulation system has been developed. This chapter also describes the direct 2D and 3D kinematic models and the differential kinematics of the robot's segments. The segments' control system is modeled and simulated.

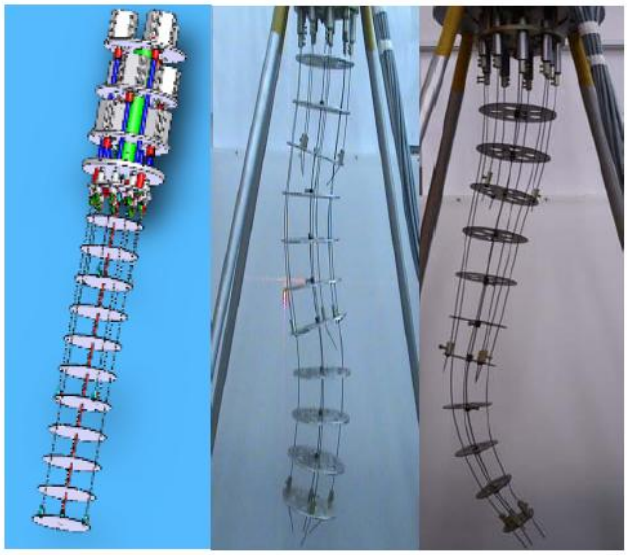

Figure 1 Hyper-redundant manipulator a) CAD representation b) Cylindrical shape c) tronconic shape

Some Matlab simulations are performed in order to track the evolution of the control cables in the 2D and 3D cases. In the end of the chapter, a closed loop video based segment control system is proposed, in which the artificial video system measures the current curvature angles of the segments.

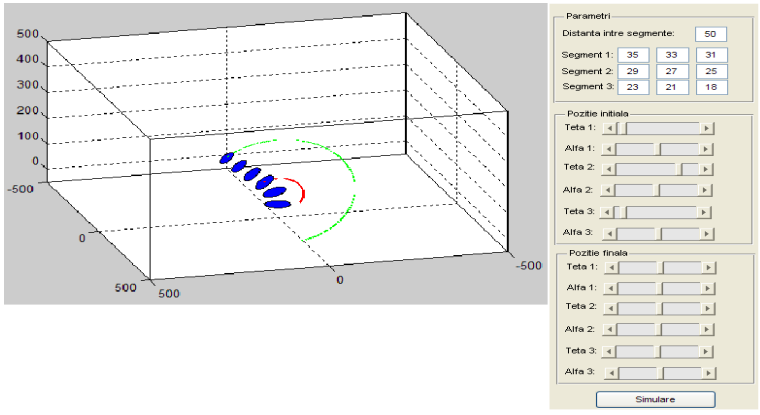

Figure 2. Graphical interface of the simulator

Within **Chapter 5** – Tele-operation system for a hyper-redundant robot – a remote operation system has been designed,

which allows the control of a 3-segment hyper-redundant arm, allowing a human operator control the shape of the arm from a remote location.

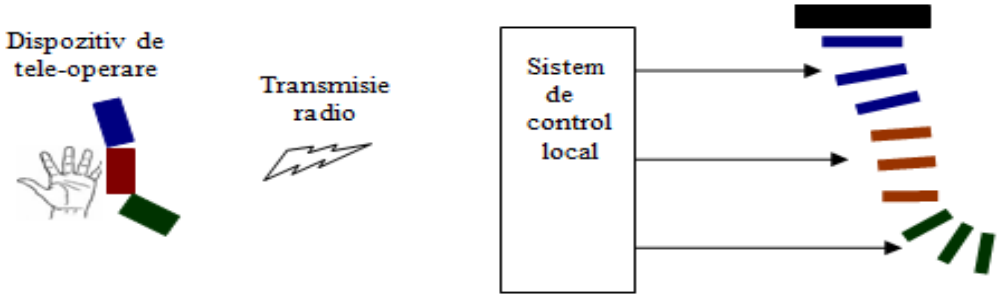

Figure 3 . Structure of the tele-operation system.

The tele-operation device is built of three segments that remotely control three segments of the robotic arm. The segments inclination angles of the device are transmitted to the local control system via radio waves. The control of the robot's segments is achieved via MMA7260Q 3-axis MEMS accelerometers. Each accelerometer is associated with a robotic segment, which is remotely controlled. The inclination of the control segment is calculated with the inclination of the corresponding accelerometer.

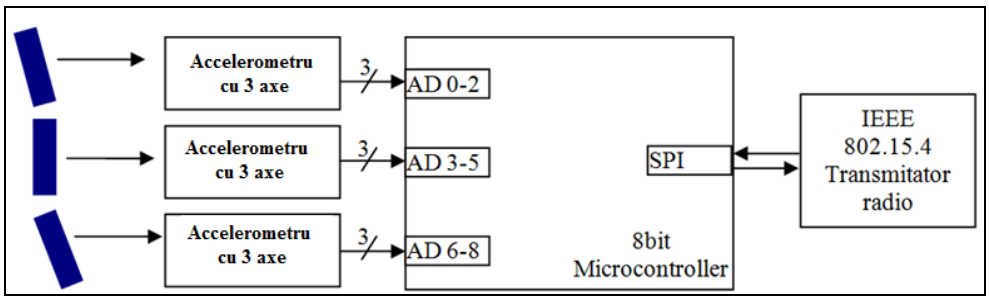

Figure 4. Structure of the tele-operating device.

The accelerometers have been integrated by a software application in order to transmit the data to the local control system.

For data transmission to the local robot's controller, a wireless communication system has been developed.

The implementation of a communication system is based on the IEEE 802.15.4 standard. The network is formed by a coordinator connected to the local computer which controls the robot and three end devices connected to the tele-operation device segments.

In order to test the tele-operation device in real time, the robot Matlab simulator is used. The simulator receives the data from the coordinator via the USB interface.

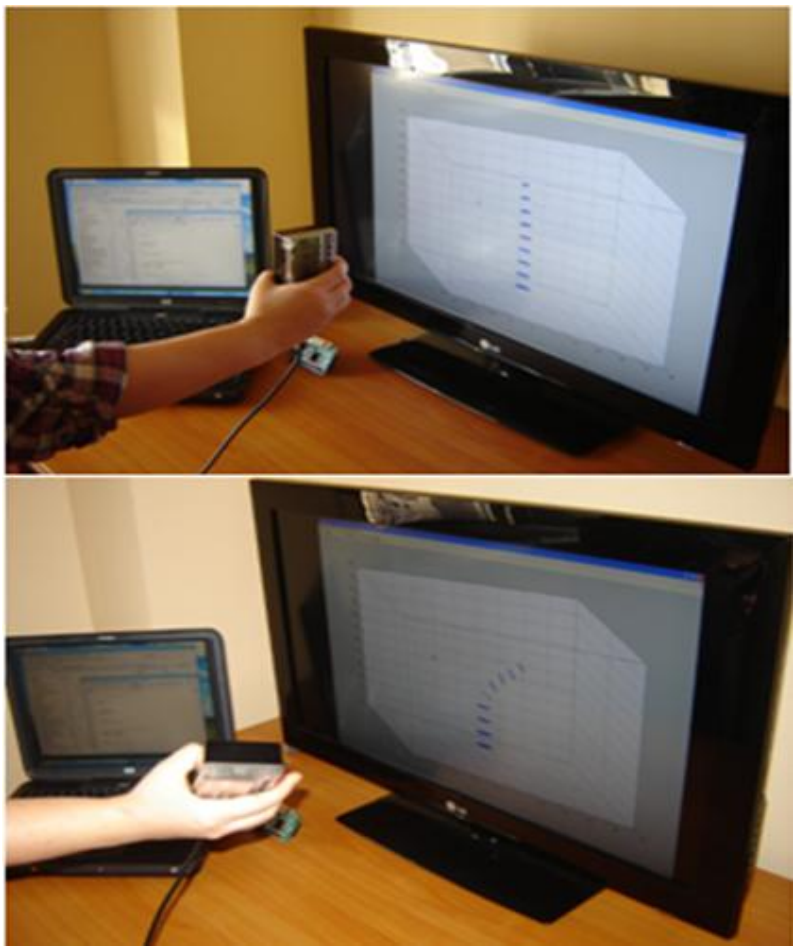

Figure 5. Simulation of the tele-operation system

For a better understanding of how the hyper-redundant robot functions in the real world, a VRML 3D model of the robot has been created. The VRML model uses the Matlab simulation data as input and the robot shape is displayed in a VRML capable browser.

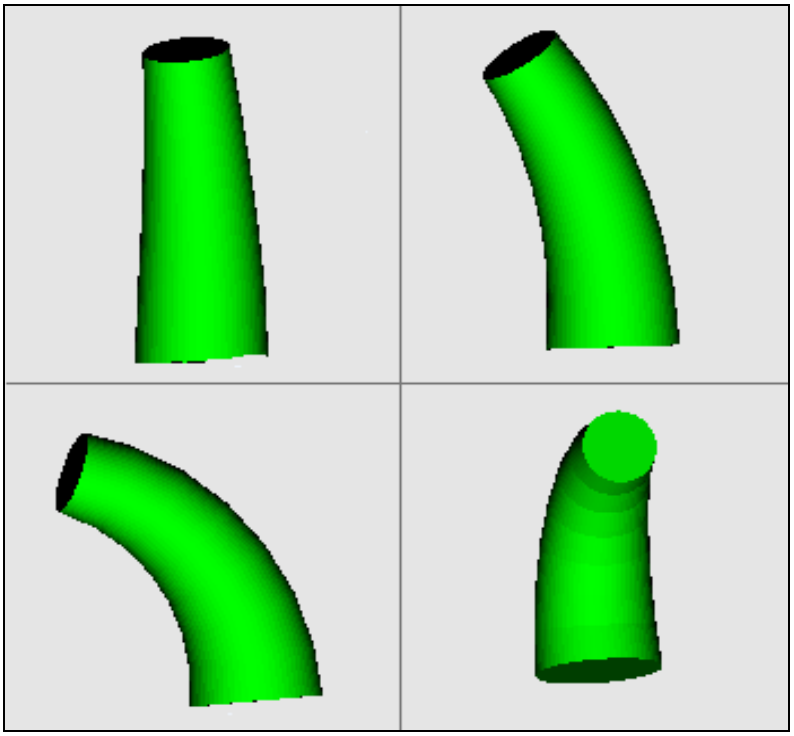

Figure 6. Images taken during 3D simulation of the robot using VRML

Contributions

The personal contributions acquired in this thesis are enumerated below:

- A complete investigation of the characteristics of the most important hyper-redundant robotic structures.
- The synthetic presentation of main hyper-redundant robots actuation systems.

- The study of kinematic, dynamic and differential models of a hyper-redundant robot
- The presentation of a cooperative control method for hyper-redundant arms.
- The presentation of a fuzzy controller for hyper-redundant robots.
- The analysis of alternative control methods for hyper-redundant robots, based on video cameras and identification of advantages and disadvantages of using these methods.
- Development of mathematical models for a hyper-redundant tronconic robot:
  - A Matlab based simulator has been developed;
  - The 2D and 3D kinematic models have been created;
  - The hyper-redundant robot's segments controller has been modeled and simulated;
  - The differential kinematic model of the robot's segments has been determined;
  - A series of Matlab simulations have been performed in order to validate the robot calculated model;
  - A closed loop control of the segments has been proposed, based on an artificial vision system, which measures the current curvature angles of segments.
- The design of a tele-operation system for the hyper-redundant robot.
  - The accelerometers have been integrated with a software application in order to transfer the data to the local controller;

- An IEEE 802.15.4 based wireless communication system has been implemented;
- A control algorithm has been developed in order to achieve the reference position for the 2D case;
- The real time evolution of the tele-operation system has been tested using the Matlab simulator;
- A VRML 3D model of the hyper-redundant arm has been developed.