Preface

Through its evolution, the field of Robotics and Mechatronics has proven itself as a unifying interdisciplinary and intelligent engineering science paradigm that fuses, permeates, and comprehends modern engineering science and technologies while supporting new ways of thinking (lateral and vertical), innovations, design methodologies, etc. It is opening new horizons in all fields due to the stimulation of synergy, fusion, and interdisciplinary efforts.

Robotics and Mechatronics synergistically fuse mechanics, electrical, electronics, software and computer engineering, sensors and perception, informatics and intelligent systems, intelligent and real time control, optics, smart materials, actuators, artificial intelligence, precision and manufacturing engineering, advanced modeling and simulation, virtualization and visualization, etc. into a unified framework that enhances both the design process of products and the manufacturing processes.

The synergy in the field of Robotics and Mechatronics enables innovative and higher levels of interdisciplinary research that lead to high quality of performance, functionality, smartness, flexibility and modularity, reliability, adaptability, intelligence, precision, robustness, power efficiency, maintainability, spatial integration of subsystems, miniaturization, embedded lifecycle design, sustainable development, and cost-effective approach. In addition, it enables the creation, design, and support of new concepts for realizing intelligent human-oriented machines that coordinate and cooperate intelligently with their human users.

This handbook with its 30 chapters contributes with the state-of-art of research advancement in the field of Robotics and Mechatronics, and provides relevant theoretical knowledge, practices, technological evolution, and new findings.

This handbook presents up-to-date knowledge and helps to prepare engineers and scientists who are looking to develop innovative, challenging, intelligent, bioinspired, and value added ideas for autonomous and smart interdisciplinary products and systems to meet today’s and future most pressing challenges.

Chapters 1-9 present robotics-mechatronics and biomimetics as an interdisciplinary engineering science.

Chapter 1 discusses the characteristics of the kinematic synergy in human locomotion and develops a locomotion control system for a biped robot that enable it to produce gaits and change them based on the kinematic synergy to tackle the redundancy problem in the motion planning of the biped robot.

Chapter 2 presents the development of Hexapod locomotive of a Micro-Electro Mechanical Systems (MEMS) microrobot with Pulse-type Hardware Neural Networks (P-HNN) locomotion controlling system. The MEMS microrobot emulated the locomotion method and the neural networks of an insect with small size actuator, link mechanisms and P-HNN.
Chapter 3 describes a control method for a multi-joint robotic manipulator using Electromyogram (EMG) signals for operating a glovebox. The system uses a Probabilistic Neural Network (PNN) to estimate the user’s intended motion from EMG patterns, and generates a control command for the glovebox and robotic manipulator corresponding the estimated motions.

Chapter 4 shows that robot-assisted rehabilitation systems can to be very helpful in neuromotor rehabilitation because it is possible to deliver interactive and repeatable sensorimotor exercise and monitor the actual performance continuously. By using biosensors it would be possible to recognize different emotional state such as excited, bored, over-stressed, etc. at each subject (human). Accordingly, it would be necessary to adjust the difficulty level of the rehabilitation task to encourage the non-motivated subjects during the therapy. To achieve this, machine learning techniques is adopted to classify the emotional state using the features of the biofeedback sensory data.

Chapter 5 covers first the polarization-based visual behavior in the animal kingdom. Then, it goes in depth with the bio-inspired applications based on polarization in computer vision and robotics with aim to have a comprehensive survey highlighting the key principles of polarization based techniques and how they are biologically inspired.

Chapter 6 aims to present the state of the art in biomimetic robotic fishes and introduces the required features supporting the development of biomimetic swimming robots including swimming modes, body and fin shapes, and actuation mechanisms. Based on these design principles and without any optimization, a tuna-mimetic robot called UC-Ika 1 is designed where the undulatory motion and the shape of tuna are mimicked and an appropriate actuator system is selected. The robot is then fabricated and tested under water. In addition, another robotic fish (UC-Ika 2) is designed and fabricated and this design is based on the optimal nature of two fishes, tuna and bird-wrasse. On the contrary of UC-Ika 1 which is specialized for cruising, UC-Ika 2 is specialized for cruising and maneuvering.

Chapter 7 analyzes a propulsive force generated from pectoral fins for a manta-like fish robot which is one of rajiform-type fish robot in a classification of swimming mechanism of fishes, from fluid dynamics aspects. The fishes of this type swim underwater with two pectoral fins. For the developed robot fish, a diving method is proposed and the usefulness of the developed method is demonstrated through numerical simulations and testing it using the developed manta-like fish robot.

Chapter 8 discusses the design of robot with worm-like principle of locomotion. The original construction of asymmetrical dry friction mechanisms was offered. The mathematical model of a robot considering as mobile vibration-driven system consisting of two solid bodies connected by the piecewise linear viscous-elastic element and the electromagnetic drive. The system moves along a rough surface using friction asymmetry at the mass-surface contact. Both shock-free and shock modes of motion are considered; dependences of the average velocity of translational motion of the system on the frequency of the external periodic control voltage are obtained. In addition, this chapter contains analysis of Worm-Like Robot (WLR) movement with different parameters.

Chapter 9 describes an interactive learning system to assist positive change in the preference of a human toward the true preference. The chapter describes awareness based recommendation toward human adaptive and friendly interactive recommendation system. For considering preference shift of a user, the chapter proposes user-centered interactive recommendation by visualizing both the recommendation space with prepared recommendation plans and the user’s preference trace as the history of the recommendation in it.
Preface

Chapters 10-12 introduce research topics related to advancement of Robotics and Mechatronics research in the medical and rehabilitation field.

Chapter 10 guides through the historical development of the most important surgical robotic systems, and provides references and lessons learnt for current engineers facing similar challenges. Special emphasis is put on surgical robotic systems’ validation, assessment and clearance, as the most commonly cited barrier hindering the wider deployment of a system.

Chapter 11 presents the upper and lower human limbs movements, a review of mechanical systems used for rehabilitation of upper and lower limbs, as well as the mathematical model of cable-driven manipulators. The experimental tests of the cable-driven manipulator for upper and lower limb rehabilitation movements are presented along with the future research directions in rehabilitation robots.

Chapter 12 contributes the development of new robotic exoskeleton device designed to be lightweight, comfortable, and safe to use for gait rehabilitation for stroke patients, which were lacking in the existing devices. Another contribution is the establishment of new manufacturing technique that allow custom exoskeleton component for each individual patient. In addition, the chapter introduces the development of advanced model-based FF controller that achieves fast and accurate tracking performance.

Chapters 13-17 deal with the development of control and stability techniques for Robotics and Mechatronics systems.

Chapter 13 proposes structural condition monitoring for buildings and mechanical structures using a new nonlinear filtering method called Derivative-Free Nonlinear Kalman Filtering. The considered filter makes use of an exact linearization transformation of the structure’s dynamical model in accordance to differential flatness theory and of an inverse transformation that enables to obtain estimates for the state vector elements of the initial model. A multi-DOF building or mechanical structure is modeled as a set of coupled nonlinear oscillators that can be subjected to external excitation. The response of the structure is recorded and compared against the response generated by the Derivative-Free Nonlinear Kalman Filter under the assumption of a damage-free model. The efficiency of the proposed method is tested through simulation experiments.

Chapter 14 presents the development of the dynamic model based on Newton Euler formalism of a Vertical Take-Off and Landing (VTOL) type Unmanned Aerial Vehicle (UAV) known as the quadrotor. In addition, it introduces the development of a simulation environment on which the developed model is verified. Four control algorithms are developed to control the quadrotor’s degrees of freedom: a linear PID controller, Gain Scheduling-Based PID Controller, nonlinear Sliding Mode, and Backstepping controllers. The performance of these controllers are tested and compared in terms of their dynamic performance, stability and the effect of possible disturbances.

Chapter 15 describes kinodynamic motion planning and its application. Kinodynamics is the discipline that tries to solve kinematic and dynamical constraints simultaneously. In addition, Kinodynamic motion planning is useful for generating the control input in a simple way as it can define the control input in one step by considering the kinematics and dynamics simultaneously after designing the controller. The Kinodynamic motion planning and its application to a flying robot are presented and discussed.

In Chapter 16, trajectory-tracking performance of different types of widely used control strategies (i.e. classical, robust, and intelligent controllers) are comparatively evaluated. To accomplish this evaluation, PID, sliding mode, and fuzzy logic controllers are implemented on a biomimetic robot hand finger model and the simulation results were quantitatively analyzed and discussed.
Chapter 17 compares different control strategies using the example of the cooling fan control of a mobile machine. Three different types of controllers have been investigated in several variations. These controllers are: fuzzy control, PI(D), and Model Predictive Control (MPC). Fourteen different criteria have been used to support the evaluation process.

Chapters 18-24 cover application and development of Robotics and Mechatronics systems with the main focus on mobile robots navigation: land, water, and air.

Chapter 18 deals with hexapod walking robot design and operation. The chapter introduces a wide overview of the state of the art on hexapod walking robots by referring both to the early design solutions and the most recent achievements while it identify the main design challenges that influence the technical feasibility and performance of these systems. The proposed design procedure takes into account mechanical structure, leg configuration, actuating and drive mechanisms, payload, motion conditions, walking gait, control system. A case of study is carefully described as referring to previous experiences at Laboratory of Robotics and Mechatronics by University of Cassino and Southern Lazio.

Chapter 19 presents recent mechatronics developments to create terrestrial mobile robots capable to cross obstacles and keep their stability on irregular grounds. Obstacle-crossing is both considered with quasi-static models at low speed and dynamic models at high speed. All of the developed robots use wheeled propulsion because of its high efficiency on smooth grounds and improve their performance on irregular grounds with suitable additional mobilities in their frame that bring them closer to legged locomotion (hybrid locomotion).

The goal of Chapter 20 is to enable a nonholonomic mobile robot to track a specified trajectory with minimum tracking error. The tracking performance of the controller is illustrated for different trajectories with computer simulation using Matlab/Simulink. In addition, open-loop response of an experimental mobile robot is investigated for these different trajectories while the performance of the proposed controller is compared to a standard PID controller.

Chapter 21 addresses the main issues of Navigation, Guidance, and Control (NGC), and vision system of Autonomous Surface Vessels (ASV). Recently, these issues compose research problems and conduct related research findings. The hardware and subsystem of ASVs is introduced. Visual ASV is applied increasingly in complex and unknown environment with increasing demand of obstacles avoidance. Two examples of visual applications are demonstrated. One is riverbank identification using color segmentation and Hough Transform, and the other is bridge detection using optical flow.

Chapter 22 provides a framework for radio frequency visual simultaneous localization and mapping problems for a team of agents consisting of three blimps and beacons. In a cooperative system, each agent must establish reliable data sharing during a mission. Under these conditions, a framework was proposed which allows each agent to share the local information using peer-to-peer networking schemes. In addition, the chapter addresses the problem of detection features using SIFT algorithms while considering the sea surface as the working environment. The framework of the research consists of two types of agents, the beacon representing the static agent and blimp representing the homogeneous mobile agent.

Chapter 23 presents an integrated approach for Mission Design of a team of Service Robots, which is operating in partially known indoor environments such as libraries, hospitals, or warehouses. The Bump-Surface concept is used to represent the entire robots’ environment through a single mathematical entity and an optimization problem is formulated representing the aggregation of the path lengths and the constraints. Team robots are requested to serve a number of service stations while taking into account movement safety and other kinematical constraints. A modified Genetic Algorithm with parallel populations is used for solving the problem of mission design of a team of service robots on the constructed Bump-Surface. Simulation examples are presented to show the effectiveness of the presented approach.
Chapter 24 describes an approach of secure navigation systems for wheelchairs, using RF signal triangulation and Extended Kalman Filter in conjunction with Genetic Algorithm for indoor trajectory optimization. Initial system is implemented and tested at virtual environment with conception of supervision and control systems for mobile robots, which are capable of operating and adapting in different environments and conditions. Validation of this environment is made in a nonholonomic mobile robot and in a wheelchair; both used an embedded control rapid prototyping for best navigation strategy implementation. ToF (Time-of-Flight) of the RF digital signal interacting with beacons for computational triangulation in the way to provide a pose estimative at bi-dimensional indoor environment, where GPS system is out of range, are depicted.

Chapter 25 describes the robotic CAM system proposed from the viewpoint of robotic servo controller for an articulated industrial robot RV1A. Then, a reverse post-processor is proposed for the robotic CAM system to online generate the original CL data from the NC data post-processed for a five-axis NC machine tool with a tilting head. The developed CAM system has a high applicability to other industrial robots with an open architecture controller whose servo system is technically opened to end-users, and also works as a straightforward interface between a general CAD/CAM system and the industrial robots. In order to show the efficiency of the developed system, an application of the industrial robot incorporated the robotic CAM system is introduced.

Chapter 26 introduces a novel highly concurrent task-planner for distributed multi-robot systems. The system deals with two issues: a) path-planning and b) robotic-tasks scheduling for industrial feed-lines. A model of distributed task planners is proposed to autonomously reconfigure and synchronize robotic actions throughout exponential functions that dynamically change priorities as required by the robotic primitives: sense, plan, and act, in accordance to spatiotemporal industrial events. The task-oriented approach concerns carry-and-fetch and dispatching materials, as well as the robots’ ability to navigate to different goals. Numerical simulation of mathematical formulation and real experiments are presented to illustrate the parallel computing capability, and the distributed robot’s behavior.

Chapter 27 introduces the ongoing research and development of robotic and mechatronics systems applied in medical treatment, surgical operation, automated manufacturing, and high-speed production. Two recent robotic researches are included in this chapter to show the technical methodologies of computer-aided 3D modeling, computational simulation, engineering analysis, prototyping, and experiment in design and development of robotic systems.

Chapter 28 proposes a new method of assessment for measuring practical intelligence acquired by engineering students after performing engineering laboratory classes. The novices-experts approach is be used in designing the assessment instruments; based on the behaviors’ of students (novices)/experts observed and novices/experts representative work-related situations. To achieve the objective, the experts undertake practical technical problem-solving activities in a specific laboratory tasks, and in-depth observation and interviews on experts’ behavior will be carried out to establish a valid and reliable practical intelligence instrument. The practical intelligence can be measured by calculating the difference between participants’ ratings and the experts’ ratings; the closer the novices with experts, the higher the practical intelligence acquired by novices.

Chapter 29 focuses on the motivating and engagement aspects of robotics technical design experiences for youth participating in two different after school robotics programs: the Digital Youth Network (DYN) and Robot Diaries (RD). The chapter analytically describes and compares the relationship between programmatic goals of each program and participant experiences. The chapter offers recommendations for the design of robotics programs for youth and points to the importance of the role of audience, materials selection, instructor roles, and instructor knowledge.
Chapter 30 presents a case study of mechatronic system design and prototyping of a two-axis solar tracking system ST100 utilizing microcontroller OOPic. Two stepper motors adjust the solar panel’s rotation and tilt about the horizontal axis and the vertical axis according to the information from three cadmium sulfide photo-resistors that are mounted on the top and bottom edges of the solar cell panel. This gives it the ability to track the movement of the sun and align the solar panel to face the sun at all time.

This handbook targets senior and graduate students in Robotics, Mechatronics, and relevant scientific fields, engineers and scientists, Robotics and Mechatronics engineers, researchers, and practicing engineers who wish to enhance and broaden their knowledge and expertise on the development, technologies, knowledge, practices, applications, and the evolution of Robotics and Mechatronics field.

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