MACHINE LEARNING FOR COMPLEX AND UNMANNED SYSTEMS

Edited by
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Machine Learning for Complex and Unmanned Systems

This book highlights applications that include machine learning methods to enhance new developments in complex and unmanned systems. The contents are organized from the applications requiring few methods to the ones combining different methods and discussing their development and hardware/software implementation. The book includes two parts: the first one collects machine learning applications in complex systems, mainly discussing developments highlighting their modeling and simulation, and hardware implementation. The second part collects applications of machine learning in unmanned systems including optimization and case studies in submarines, drones, and robots. The chapters discuss miscellaneous applications required by both complex and unmanned systems, in the areas of artificial intelligence, cryptography, embedded hardware, electronics, the Internet of Things, and healthcare. Each chapter provides guidelines and details of different methods that can be reproduced in hardware/software and discusses future research.

Features

- Provides details of applications using machine learning methods to solve real problems in engineering
- Discusses new developments in the areas of complex and unmanned systems
- Includes details of hardware/software implementation of machine learning methods
- Includes examples of applications of different machine learning methods for future lines for research in the hot topic areas of submarines, drones, robots, cryptography, electronics, healthcare, and the Internet of Things

This book can be used by graduate students, industrial and academic professionals to examine real case studies in applying machine learning in the areas of modeling, simulation, and optimization of complex systems, cryptography, electronics, healthcare, control systems, Internet of Things, security, and unmanned systems such as submarines, drones, and robots.

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Contents

Preface

Nowadays, in a very huge number of engineering applications one can infer the use of machine learning methods. From the sensing of data, one can infer the necessity of signal conditioning techniques, data classification algorithms, signal processing, and control of devices or loads. Obviously, not all applications can be developed using the same machine learning methods, so this book includes a collection of recent works, which focus on special cases in the areas of modeling, simulation, optimization and hardware implementation of complex and unmanned systems. These topic areas require special machine learning methods, as for example for the classification of data acquired by different types of sensors and video-cameras, signal processing and the control of motors, wheels, and other loads or actuators. In this manner, the sixteen chapters in this book emphasize the usefulness of machine learning methods, not only for theoretical problems but also for real case studies with real experiments.

Part 1 is devoted to complex systems and includes seven chapters. Chapter 1 introduces a neural network model for machine learning tasks, but the authors found that simple echo state networks (ESNs) can be used instead. In ESNs, only the output layer weights are calculated by linear regression, which has a low computational cost. The study shows how ESNs with improved reservoir creation can solve classification tasks using simulated data and public databases. Chapter 2 discusses the challenge of monocular camera localization due to constant changes and proposes a review of state-of-the-art methodologies for this task. Traditional methods use end-to-end training with a large dataset, but this study presents Continual Learning (CL) strategies such as distillation, weights optimization, dynamic architectures, incremental labels, and latent replay to avoid the need for a large dataset and catastrophic forgetting. The aim is to describe the benefits and limitations of these methods for camera localization tasks from a single image. Chapter 3 proposes a dataset of images of three distinct fish species, each with a unique number of images, which are trained in different convolutional neural networks (CNN) for species identification applications. The performance metrics obtained from the proposed dataset show that the YOLOV5 and RESNET models achieved a precision of 95% and 92%, respectively, and were evaluated on edge computing devices. The study plans to increase the images and species in the database to train algorithms for identifying more fish species. Chapter 4 presents a regression model that utilizes regression tree, random forest, and convolutional neural networks to model the nonlinear behavior of power amplifiers. The use of recursive subset partitioning with the regression tree model provides a fast runtime and highly accurate output estimates without overfitting. The ensemble model RT offers a single-step iteration solution for modeling sparse AM/AM behavior in a cascade setup that drives a Class AB power amplifier, which can address residual distortion present in the direct-conversion transmitter by tuning the parameters. Experimental results demonstrate the effectiveness of the proposed model for a wideband of LTE signals with varying input power levels. Chapter 5 highlights the increased use of video surveillance for security and operational efficiency and the need for effective data analysis techniques. The chapter focuses on anomaly detection in video surveillance systems, which requires unsupervised or semi-supervised learning techniques. The study describes the use of convolutional autoencoders, variational autoencoders, Long Short-Term Memory networks, and Generative Adversarial Networks for anomaly detection in video surveillance, including theoretical aspects and practical examples. Chapter 6 presents tuberculosis (TB) as a leading cause of mortality globally, with a 30% increase in the mortality rate. Reliable, fast, and sensitive diagnostic tests are needed for TB and/or COVID-19 to control disease transmission. Artificial intelligence and deep learning have been used to develop computer-assisted diagnosis systems for pulmonary diseases, offering high sensitivity and specificity values that surpass those of the human eye. Chapter 7 explores the variability present in frequencies of analog hardware and applies a charge-controlled memristor model for hardware security. The study focuses on using memristors in physical unclonable functions based on ring oscillators and evaluates the performance of the PUF response using various metrics for hardware security. The study demonstrates that memristive PUFs exhibit excellent metrics under diverse conditions of system complexity.

Part 2 is devoted to unmanned systems and includes nine chapters. Chapter 8 discusses the challenge of developing an artificial pilot capable of autonomously flying a drone in autonomous drone racing. Learning-based methods propose training an artificial pilot to associate sensorial data with fly commands, but current approaches cannot consider future events, such as an incoming turn. The study proposes augmenting the temporal analysis to consider data from future events observed through visual data and associated with flight commands optimized to follow a flight trajectory. The study discusses this approach in the context of the state of the art and an experimental framework to assess its effectiveness. Chapter 9 proposes optimizing UAV flight control's performance using metaheuristics and comparing two relevant AI techniques, Differential Evolution and Accelerated Particle Swarm Optimization algorithms. The study also applies two control techniques, Sliding Mode Control and Proportional-Integral-Derivative control. The study presents UAV model development, trajectory methodology, and the application of metaheuristics to adjust controller parameters, followed by the results and discussion of tests for adjusting controller parameters and trajectory tracking. Chapter 10 focuses on object classification in aerial navigation using texture as an important feature. The study presents a classification model that uses transfer learning and wavelet-based features as an additional feature extraction method, achieving a 53% accuracy using the Describable Texture Database. The study validates the results using a virtual world in the Gazebo simulator and creates a new Synthetic Aerial Dataset of Textured Objects, showing generalization of knowledge for some classes of the database. Chapter 11 explores using UAVs for air-ground communications to improve coverage in areas with poor or nonexistent coverage, with a focus on fifth-generation mobile communication (5G). The behavior of Air Base Stations (ABS) is analyzed to determine the coverage percentage over a simulation time, taking into account random disturbances. The analysis is conducted by simulating a quadrotor-type UAV and measuring power levels received by ground users to determine the effective coverage area. Chapter 12 presents a review of the literature on the topic of noise produced by UAVs. The aim of the review is to describe the effects of noise on society, summarize past audio analysis of noise produced by popular UAV models, and revise recent techniques on noise mitigation. The chapter concludes with potential research avenues and insights extracted from the review. Chapter 13 reviews the Neural Radiance Fields (NeRF) methodology and its latest works in computer vision and robotics, with a focus on aerial robotics applications. NeRF has become a state-of-the-art technique for generating new synthetic views due to its deep learning-based approach. The chapter also briefly discusses other potential applications and works proposing improvements to the original formulation, as well as potential opportunities for using NeRF in Unmanned Aerial Vehicles (UAVs) or drones. In Chapter 14, a small drone equipped with an OAK-D smart camera is used to perform autonomous flight and spatial AI for warehouse inspection. The OAK-D computes depth estimation and neural network inference on its chip, allowing for package scanning by detecting QR and bar codes, and a person detector for safe flight. The drone localization is performed using RGB-D ORB-SLAM, enabling autonomous flight in a GPS-denied environment, and the experiments show that the inspection task can be easily distributed using multiple drones. Chapter 15 discusses the use of Cognitive Dynamic Systems (CDS) as a framework for designing complex and intelligent cyber-physical systems. CDS is inspired by human cognition, mimicking the human brain and consisting of perception-action cycles, memory, attention, and intelligence. The approach can provide adaptation and self-modification, making it suitable for proactive unmanned vehicle systems and other applications that require machines to interact with the physical world and operate autonomously. Finally, Chapter 16 shows a study that analyzes the classification of EEG signals using machine learning algorithms, such as: discriminant line analysis, decision trees, k-nearest neighbors, naive Bayes, and support vector machines. The study presents the different extracted characteristics related to motor and imaginary movements to train the different signal classification algorithms selected. The study concludes with exemplary performance in the classification of EEG signals that allows them to be used in scenarios such as robotic movement control, prosthetics, robotics, and electronic wheelchairs.

About the Editors

Jose Martinez-Carranza is a Full-Time Principal Researcher B (equivalent to Associate Professor) in the Computer Science Department at the Instituto Nacional de Astrofisica Optica y Electronica (INAOE). In 2015, he was awarded the Newton Advanced Fellowship granted by the Newton Fund and the Royal Society in the UK. Currently, he holds an Honorary Senior Research Fellowship in the Computer Science Department at the University of Bristol in the UK. He leads a research team that has won international competitions such as 1st Place in the IEEE IROS 2017 Autonomous Drone Racing competition and 1st Place in the Regional Prize of the OpenCV AI Competition 2021. He also served as General Chair of the International Micro Air Vehicle conference, the IMAV 2021. In 2022, he joined the editorial board of the journal "Unmanned Systems". His research focuses on vision-based methods for robotics with applications in autonomous and intelligent drones.

Everardo Inzunza-González received his Ph.D. degree in Electrical Sciences from UABC Mexico in 2013, and the M.Sc. degree in Electronics and Telecommunications from the Scientific Research and Advanced Studies Center of Ensenada (CICESE) in 2001, the B.Sc. degree in Electronics Engineering from Culiacan Institute of Technology, in 1999. He is currently a full-time Professor and Researcher of Electronics Engineering at Universidad Autónoma de Baja California (UABC-FIAD) Mexico. He is currently a reviewer for several prestigious journals. His research interest includes the Internet of things, Network Security, Data Science, Artificial Intelligence, Machine-Learning and Deep-Learning, Wireless Communication, Image Processing, WSN, Pattern Recognition, Wearable Devices, Embedded Systems, FPGA, SoC, Microcontrollers, Chaotic encryption, Image encryption, Image enhancement, Image processing, Chaotic oscillators, and Applied Cryptography.

Enrique Efrén García-Guerrero studied physics engineering at the University Autonomous Metropolitana, Mexico, and received the Ph.D. and M.Sc. degree in optical physics from the Scientific Research and Advanced Studies Center of Ensenada (CICESE) Mexico. He has been with the Facultad de Ingeniería, Arquitectura y Diseño of the Universidad Autónoma de Baja California (UABC-FIAD) Mexico since 2004. His current research interest includes Image enhancement, embedded systems, chaotic cryptography, artificial intelligence, machine-learning, deep-learning, neural networks, digital image processing, and optical systems.

Esteban Tlelo-Cuautle received a B.Sc. degree from Instituto Tecnológico de Puebla (ITP) México in 1993. He then received both M.Sc. and Ph.D. degrees from Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), México in 1995 and 2000, respectively. During 1995-2000 he was with the electronics-engineering department at ITP. In 2001 he was appointed as Professor-Researcher at INAOE.

He has been Visiting Researcher in the department of Electrical Engineering at University of California Riverside, USA (2009-2010), in the department of Computer Science at CINVESTAV, México City, México (2016-2017), and Visiting Lecturer at University of Electronic Science and Technology of China (UESTC, Chengdu 2014-2019). He has authored five books, edited 12 books and more than 300 works published in book chapters, international journals and conferences. He is member in the National System for Researchers (SNI-CONACyT-México). His research interests include integrated circuit design, optimization by metaheuristics, fractional-order chaotic systems, artificial intelligence, security in Internet of Things, and analog/RF and mixed-signal design automation tools.

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Part I

Machine Learning for Complex Systems