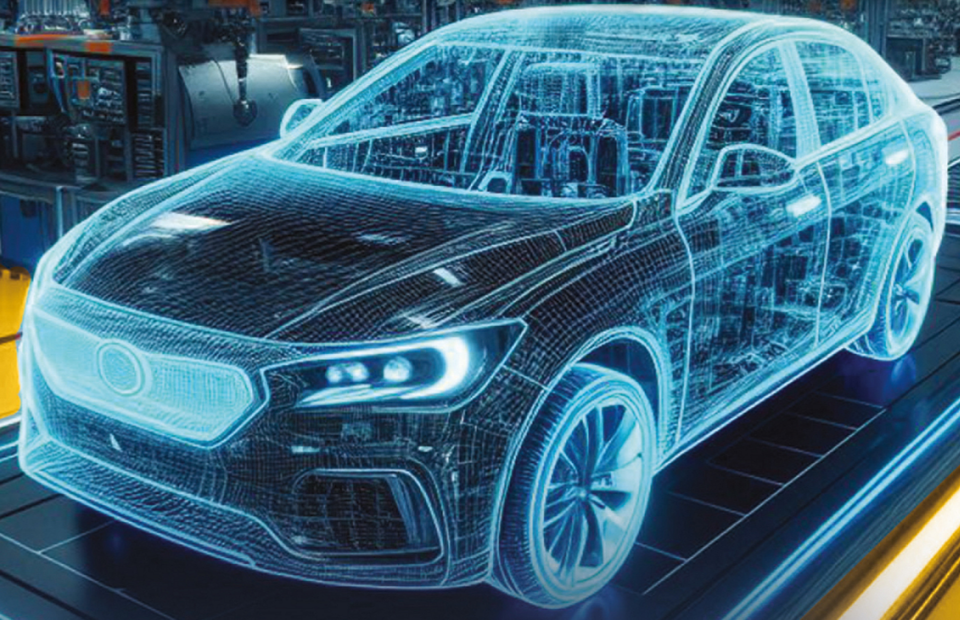
ARTIFICIAL INTELLIGENCE-ENABLED DIGITAL TWIN *for* SMART MANUFACTURING



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Preface

In the rapidly evolving landscape of modern manufacturing, the integration of cutting-edge technologies has become imperative for businesses to remain competitive and adaptive. Among these technologies, Artificial Intelligence (AI) stands out as a transformative force, revolutionizing traditional manufacturing processes and making the way for the era of smart manufacturing. At the heart of this technological revolution lies the concept of the *Digital Twin*—an innovative approach that bridges the physical and digital realms of manufacturing. By creating a virtual representation of physical assets, processes, and systems, organizations can gain unprecedented insights, optimize operations, and enhance decision-making capabilities.

This timely book explores the convergence of AI and Digital Twin technologies to empower smart manufacturing initiatives. Through a comprehensive examination of principles, methodologies, and practical applications, we explain the transformative potential of AI-enabled Digital Twins across various facets of the manufacturing lifecycle. From design and prototyping to production and maintenance, AI-enabled Digital Twins offer multifaceted advantages that redefine traditional paradigms. By leveraging AI algorithms for data analysis, predictive modeling, and autonomous optimization, manufacturers can achieve unparalleled levels of efficiency, quality, and agility.

This book explains how AI enhances the capabilities of Digital Twins by creating a powerful tool that can optimize production processes, improve product quality, and streamline operations. Note that the Digital Twin in this context is a virtual representation of a physical manufacturing system, including machines, processes, and products. It continuously collects real-time data from sensors and other sources, allowing it to mirror the physical system's behavior and performance.

What sets this Digital Twin apart is the incorporation of AI algorithms and machine learning techniques that enable it to analyze and predict outcomes, recommend improvements, and autonomously make adjustments to enhance manufacturing efficiency. This book outlines essential elements, like real-time monitoring of machines, predictive analytics of machines and data, optimization of the resources, quality control of the product, resource management, decision support (timely or quickly accurate decisions).

Moreover, this book elucidates the symbiotic relationship between AI and Digital Twins, highlighting how AI augments the capabilities of Digital Twins by infusing them with intelligence, adaptability, and autonomy. Hence, this book promises to enhance competitiveness, reduce operational costs, and facilitate innovation in the manufacturing industry. By harnessing AI's capabilities in conjunction with Digital Twins, manufacturers can achieve a more agile and responsive production environment, ultimately driving the evolution of smart factories and Industry 4.0/5.0.

We want to express our deepest appreciation to everyone who dedicated their time and efforts to make this book a success. Furthermore, we wish to gratefully acknowledge the suggestions, help, and support of Martin Scrivener and the team at Scrivener Publishing.

Amit Kumar Tyagi
Shrikant Tiwari
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Part 1

FUNDAMENTALS OF AI-BASED SMART MANUFACTURING

1

Machine Learning Fundamentals

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Abstract
Machine learning (ML) is a topic of study focused on comprehending and developing "learning" methods, or methods that use data to enhance performance on a certain set of tasks. It is considered to be a component of artificial intelligence. The Types of learning in Machine Learning are Supervised Learning: uses labeled data for model training, Unsupervised Learning: uses unlabeled data for model training. When labeled data is not available (there is no result to predict), the learning purpose is to find hidden similarities, groups or clusters among examples, or to determine characteristics in the data structure. Reinforcement Learning: consists of a trained agent that learns on the basis of rewards or penalties. The Model techniques used in machine learning based models are: 1) Classification: prediction task of categorical values in supervised learning. 2) Regression: prediction task of continuous values in supervised learning. 3) Clustering: find groups or similarities in data in unsupervised learning. 4) Dimensionality reduction (DR): reduce the number of variables/features in data in unsupervised learning. Among the types of learning, each machine learning consists of variety of algorithms and performance measures, which is aligned with various model techniques. This chapter focuses on all the types of machine learning algorithms such as Support vector machine, Discriminant Analysis, Naïve Bayes, K nearest neighbor, K Means, Decision tree, principal component analysis, etc.

Keywords: Machine learning, supervised learning, unsupervised learning, reinforcement learning

1.1 Introduction

Computational models known as machine learning algorithms allow computers to learn from data and make judgments or predictions without the need for explicit programming. They may be divided into three primary groups: clustering, regression, and classification. Classification algorithms, like Decision Trees and Support Vector Machines, give labels or categories to incoming data. Regression methods, such as Polynomial and Linear regression, forecast continuous numerical values. Clustering methods such as K-Means and Hierarchical Clustering combine related data points without the need for predetermined labels. These algorithms are essential for a wide range of applications, such as natural

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language processing and picture identification, since they can adjust to the specific issue and goal at hand. New methods keep coming up as the area develops, which carries on the machine learning progress.

1.2 Classification

Classification algorithms are used to classify test data based on prior learning. Among them, the model learns from previous data and separates the test data into different groups.

Types of Classifiers

Binary classifier: A classifier whose results have exactly two categories is called a binary classifier [1]. Example: Normal or abnormal, yes or no

Multi-class classifier: When the results of the classifier have more than two classes, it is called a binary classifier based on multiple classifiers. Example: Different stages of skin cancer, different types of products

The classification algorithm can be further divided as shown in Figure 1.1.

1.2.1 Linear Model

1.2.1.1 Logistic Regression

The probability of test items is predicted using supervised machine learning techniques like logistic regression. A binary classifier is what logistic regression is. The data is represented as 1 or 0 in the binary output variable. However, the resulting value is between 0 and 1. The S-shaped sigmoid function is used here. Linear regression models theoretically predict values as a function of X. The general linear regression model has a simple equation expressed as shown in below Figure 1.2.

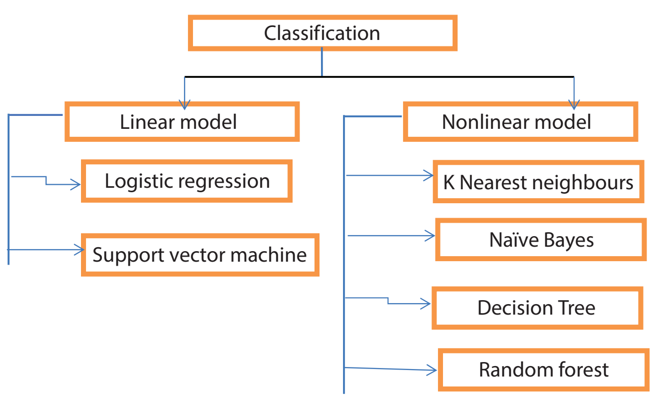

Figure 1.1 Classification of test data using algorithm.