

Multimodal Intelligent Sensing in Modern Applications

Edited by
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Dedication

To Allah, the most merciful and compassionate, who guides us through every challenge in life. His love and grace sustain us always and we dedicate this book to him, seeking his continued guidance and blessings.

To my parents, Khalil and Ilfaz, who have nurtured me with unconditional love, sacrifice, and wisdom. To my brothers, Habib and Waheed for their wholehearted assistance. To my wife, Faiza, for her being a great support system through thick and thin. To my son, Musaab, for filling my life with immense love and joy.

Masood Ur Rehman

To my wife, Mariyam, for her unwavering support, love, and patience throughout the journey of editing this book. Her encouragement has been invaluable. To my daughters, Zainab and Yusra, thank you for your joy and the inspiration you bring into my life every day. This accomplishment would not have been possible without the strength and motivation you all gave me.

Ahmed Zoha

To my biggest inspiration, my parents, Jamshed Iqbal and Nuzhut Jamshed my support system, wife: Aqsa Tariq, and my son: Zohaana Ali.

Muhammad Ali Jamshed

To my parents for all their love and for raising me in a way I am proud of. To my wife Nasira for her resolute support. To my daughters Saba, Bisma, and Hadiya for cherishing and elating my life with all the bliss and love.

Naeem Ramzan

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Preface

In recent years, there has been a significant surge in the utilization of the Internet of Things (IoT) and wireless sensors to meet escalating demands for high data rates, low latency, and ultrareliable communication in 5G/6G systems. Various strategies are under development utilizing intelligent sensing platforms to address these growing needs. Using multiple sensors has proven to be an effective approach to enhance reliability, efficiency, and user experience in diverse application scenarios across healthcare, transportation, environmental monitoring, industrial automation, and entertainment industries.

Incorporating data from multiple modalities such as visual images, radiation levels, texture details, and behavioral patterns captured by sensors like light, temperature, humidity, vision, and motion enhances the information assimilation process, leading to precise decision-making. While offering immense benefits, multi-modal sensing presents significant challenges such as energy efficiency, mobility, reliability, interference mitigation, reliability, security, and real-time processing requirements.

In an interconnected world, seamless integration of IoT with intelligent sensing platforms is essential to deliver transformative solutions. The customization and diversification of intelligent sensors require efficient techniques for designing and integrating sensors, as well as extracting valuable insights from vast amounts of multimodal data. This involves leveraging advanced sensor design, robust big data analytics, and stringent security measures to promote sustainability, spur innovation, and explore new possibilities.

To date, there is a lack of comprehensive literature that addresses design, implementation, and analytical techniques for multimodal intelligent sensing. A dedicated book focusing on these crucial aspects will not only bridge this gap but also educate readers on the key aspects of efficient sensor networks, laying the groundwork for future advancements in a smart and interconnected world. This book is a structured effort in this direction that explores the cutting-edge advancements and challenges in the realm of multimodal sensing, discussing both software and

hardware solutions. It covers a broad spectrum of topics in multimodal intelligent sensing for a range of applications, bringing together experts from various disciplines including wireless communications, signal processing, and sensor design.

Key topics discussed include sensor design, deployment efficiency, energy management, data fusion, and information extraction through machine learning, deep learning, and federated learning to showcase the latest developments in this dynamic field. By considering challenges and future prospects, the book caters to a diverse readership within the scientific community.

Chapter 1 delves into the realm of multimodal intelligent sensing, uncovering the various sensor types and the integration of multiple sensors for enhanced capabilities. The chapter also explores the applications of multimodal sensing in different sectors and the challenges and opportunities that come with this dynamic field.

Chapter 2 focuses on antennas for wireless sensors, emphasizing their crucial role as the sensory gateway for wireless networks. Readers will gain insights into fundamental antenna parameters, fabrication methods, and the different types of antennas utilized in sensing networks.

Chapter 3 discusses the sensor design for environmental monitoring, shedding light on combating deforestation through wireless sensor networks and the design considerations involved in creating effective systems for environmental conservation.

Chapter 4 explores the applicability of wireless sensors for multimodal health monitoring, detailing the use of wearable and implantable sensors, multimodal healthcare sensing devices, and the use of AI methods in healthcare systems for enhanced monitoring and diagnosis.

Chapter 5 shifts gears to sensor design for industrial automation, highlighting the role of multimodal sensing in revolutionizing industrial processes. From RF sensors to vision sensors, this chapter explores the design considerations and challenges faced in implementing multimodal sensing in industrial settings.

Chapters 6 and 7 probe hybrid neuromorphic federated learning for activity recognition and multimodal beam prediction in drone communication networks, respectively, showcasing the integration of cutting-edge technologies to enhance sensing capabilities in diverse applications.

Chapter 8 studies the domain of mind-wandering through multiple wearable sensors with the aim of detecting mind-wandering episodes through deep learning and paving ways to improve the detection of students' learning and concentration levels.

Chapters 9 and 10 investigate the advancements in remote infant monitoring systems and telehealth patient monitoring, emphasizing the design of multimodal wearable systems and secure telehealth systems for improved patient care and monitoring.

Chapter 11 explores the ethical considerations involved in the development of multimodal intelligent tutoring systems, respectively, highlighting the balance between innovation and ethical responsibility in the deployment of such systems.

Lastly, Chapter 12 paves the way for the future of multimodal intelligent sensing in the deep learning era, outlining the challenges, perspectives, and ethical considerations that will shape the evolution of sensor technology in the years to come.

This book serves as a comprehensive guide for researchers, engineers, and professionals interested in the advancements and applications of multimodal intelligent sensing systems. Each chapter offers insights, practical considerations, and future directions to inspire further innovation and exploration in this vibrant field.

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Advances in Multi-modal Intelligent Sensing

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Intelligent sensing systems play a crucial role in various fields, enabling the acquisition of valuable data for analysis, monitoring, and decision-making processes. Multi-modal intelligent sensing, with its capability to gather information from multiple sensor types and sensing parameters, has emerged as a powerful tool in diverse applications. This chapter aims to provide a comprehensive overview of multi-modal intelligent sensing, offering insights into the diverse sensor types, sensing parameters, application scenarios, and data analysis tools associated with this rapidly evolving field.

1.1 Multi-modal Intelligent Sensing

Multi-modal intelligent sensing refers to the use of multiple sensor types, such as optical, acoustic, thermal, and chemical sensors, to capture and analyze different aspects of the environment or a system. By combining data from various sensors, multi-modal sensing systems can provide a more comprehensive and holistic view of the monitored phenomenon, leading to better insights and decision-making [1].

A simple example is a system designed to monitor a remote environment, such as a home or office, with a view to enhancing security. Such a system might use a variety of sensing devices including visible light cameras, LiDAR, infra-red motion detectors, and contact microphones, each capturing unique types of data as shown in Figure 1.1. The behavior of this environment could be quite complex,

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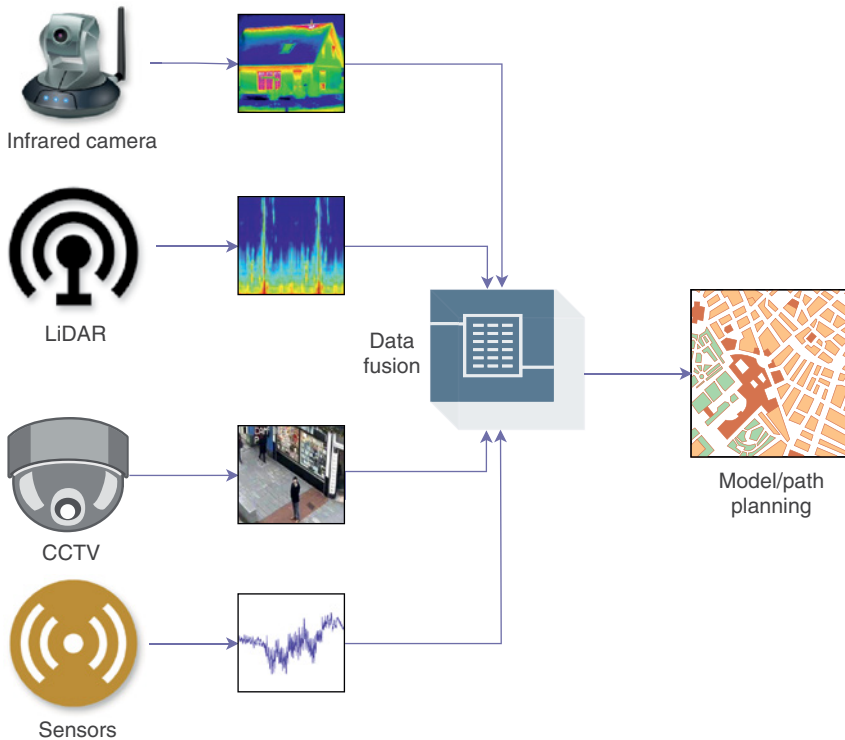


Figure 1.1 Multi-modal intelligent sensing.

for example, the sound of a door opening followed by an increase in infra-red activity and ending with the turning off of a light, could be automatically interpreted as a sequence involving an entry into the environment by an unwanted visitor (door opening), followed by movement to a specific location (increase in infra-red activity), and culminating in an attempt to allay suspicion by simulating the turning off of a light. The analysis of this complex behavior would be greatly enhanced if the system could automatically determine spatio-temporal relationships between events and classify these events into a taxonomy based on their threat to security. This could be achieved by using the information provided by the various sensing devices, organizing this information into one unified data structure through data fusion, with each type of data being a mode, and building a symbolic or semantic model of the observed events through automatic learning and reasoning using methods from artificial intelligence. The intelligent agent, influenced by this understanding, then executes actions or generates outputs accordingly [2].

The components and functionalities of this simple example can be tailored to various applications by selecting appropriate sensors, data fusion methods, and