SUSTAINABLE COMPUTING AND OPTIMIZATION

INTERNET OF THINGS IN BIOELECTRONICS

Emerging Technologies and Applications

Edited by
Hari Murthy, Marta Zurek-Mortka,
Vinay Jha Pillai, and
Kukatlapalli Pradeep Kumar

Scrivener Publishing

WILEY

Internet of Things in Bioelectronics

Scrivener Publishing
100 Cummings Center, Suite 541J
Beverly, MA 01915-6106

Publishers at Scrivener
Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

Internet of Things in Bioelectronics

Emerging Technologies and Applications

Edited by

Hari Murthy
Dept. of Electronics and Communication Engineering, School of Engineering and Technology, CHRIST (Deemed to be University), Bangalore, India

Marta Zurek-Mortka
Dept. of Control Systems, Institute for Sustainable Technologies, Radom, Poland

Vinay Jha Pillai
Dept. of Electronics and Communication Engineering, School of Engineering and Technology, CHRIST (Deemed to be University), Bangalore, India

and

Kukatlapalli Pradeep Kumar
Dept. of Electronics and Communication Engineering, School of Engineering and Technology, CHRIST (Deemed to be University), Bangalore, India

Scrivener Publishing

WILEY

This edition first published 2024 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA

For more information about Scrivener publications please visit www.scrivenerpublishing.com.

Wiley Global Headquarters
111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Library of Congress Cataloging-in-Publication Data

ISBN 978-1-394-24187-3

Front cover image provided by Wikimedia Commons
Cover design by Russell Richardson

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

Contents

Preface

The rapid convergence of technology and biology heralds a new era of evolution in the Internet of Things (IoT), a transformative force enabling interconnected devices to communicate and operate with unparalleled synergy. This is particularly true in the groundbreaking field of bioelectronics, where the fusion of biological systems with electronic devices and IoT is reshaping the landscape of bioelectronics, promising to open up new frontiers in healthcare, diagnostics, and personalized medicine.

This book aims to provide a comprehensive exploration of this exciting intersection. It delves into the principles, applications, and future directions of IoT in the realm of bioelectronics, and it is designed to serve as both an introduction for those new to the field and as a detailed reference for experienced professionals seeking to deepen their knowledge.

This timely resource explores the numerous ways in which IoT-enabled bioelectronic devices are used to monitor and enhance human health, from wearable sensors that track vital signs to implantable devices that can communicate with healthcare providers in real-time. One central theme of this book is the transformative impact of IoT on healthcare. By enabling continuous, remote monitoring of patients, IoT technologies are not only improving the accuracy of diagnostics but also making healthcare more accessible and personalized. The book also addresses the critical issues of securing health records on the internet, which are of paramount importance as we increasingly rely on interconnected devices to collect and transmit sensitive health information. Additional attention is paid to the future directions of IoT in bioelectronics and the integration of innovative areas, such as artificial intelligence, machine learning, and big data analytics, in driving the development of ever more sophisticated and capable bioelectronic systems.

We extend our heartfelt thanks to all those who have contributed to this book, including our collaborators, reviewers, and the many experts whose work has informed our understanding of this field. We also thank our readers, whose curiosity and passion for innovation drive the ongoing exploration and development of these transformative technologies. Finally, I am most grateful to Martin Scrivener of Scrivener Publishing for his help and for making this book possible.

The Editors

Acknowledgement

The editors would like to thank the management at CHRIST University for providing the necessary resources and the motivation to complete the proposed title. Rev. Dr. Fr. Jose CC, Vice Chancellor, CHRIST University and Dr. Anil Pinto, Registrar, CHRIST University for their unwavering support. Rev. Dr. Fr. Sony J Chundattu, Director, School of Engineering and Technology, CHRIST University and Dr. Iven Jose, Dean, School of Engineering and Technology, CHRIST University for ensuring that the resources required for the book are available at all times. Dr. Inbanila K, Head of Department, Department of Electronics and Communication Engineering, School of Engineering and Technology, CHRIST University and Dr. Mary Anita, Associate Dean, Head of Department, Department of Computer Science and Engineering, School of Engineering and Technology, CHRIST University for encouraging us to go ahead with the interdisciplinary topic and providing all the support to ensure that the book comes out in due time. Last and not the least, we would like to thank our family who has been the greatest source of inspiration and who have put up with our antics.

1

IoT-Based Implant Devices in Humans/Animals for Therapeutic Reasons

Chetankumar Kalaskar

Department of CSE, Poojya Doddappa Appa College of Engineering Kalaburgi, Karnataka, India

Abstract
IoT-based implant devices have revolutionized therapeutic applications in both humans and animals. These cutting-edge implants enable real-time remote monitoring and personalized treatment adjustments, reducing the need for frequent physical visits to healthcare providers. With the power of continuous data streams and real-time analysis, these implants enhance patient engagement and adherence to treatment plans. The ability to detect anomalies and device malfunctions early through data-driven insights ensures timely interventions, improving patient outcomes. Despite their transformative potential, challenges related to power management, data security, and regulatory compliance must be addressed for seamless integration. Overall, IoT-based implants hold the promise to reshape healthcare delivery and elevate patient care to new levels.

***Keywords*:** Implantable medical devices, IoT healthcare, remote patient monitoring, continuous health monitoring

1.1 Introduction

The Internet of Things (IoT) is a term used to describe the concept of connecting physical objects to the internet and enabling them to communicate with other devices and systems [1]. It refers to the network of devices, vehicles, appliances, and other items embedded with electronics, software,

Email: chetankalaskar@pdaengg.com

Hari Murthy, Marta Zurek-Mortka, Vinay Jha Pillai and Kukatlapalli Pradeep Kumar (eds.) Internet of Things in Bioelectronics: Emerging Technologies and Applications, (1–16) © 2024 Scrivener Publishing LLC

sensors, and connectivity which enables them to connect and exchange data with other devices over the internet. The ultimate goal of IoT is to make everyday objects smarter and more connected, improving the way we live and work.

IoT technology has revolutionized the way we interact with our surroundings and has enabled us to collect and process data in ways that were previously impossible. With the help of IoT, devices can communicate with each other, share data, and take action based on that data. This technology has far-reaching implications across various industries such as healthcare, transportation, agriculture, and manufacturing. It has the potential to improve the efficiency and effectiveness of various systems and processes, leading to increased productivity and reduced costs [2].

IoT-based implant devices are a rapidly growing field in healthcare, with the potential to revolutionize the way medical treatment is delivered. These devices, which are implanted inside the body, use IoT technology to collect and transmit data on a patient's vital signs and other health-related information. This information can then be used by healthcare providers to monitor the patient's health, detect potential issues, and provide timely interventions. The use of IoT-based implant devices in animals and humans for therapeutic reasons has the potential to greatly improve patient outcomes, reduce costs, and increase access to healthcare services. These devices can be used for a variety of purposes, such as monitoring vital signs, delivering medication, and providing electrical stimulation for conditions such as Parkinson's disease.

Another benefit of IoT-based implant devices is their ability to deliver medication directly to the site of the problem. For example, an implantable device could be used to deliver insulin to a patient with diabetes, or to deliver medication to a patient with a chronic pain condition. This can greatly improve the effectiveness of the medication and reduce the need for frequent injections or oral medications. While IoT-based implant devices have the potential to greatly improve patient outcomes, there are also several challenges that need to be addressed.

The Technology behind IoT-based implants rely on a combination of hardware and software technologies. The hardware components include small sensors, microprocessors, wireless communication devices, and power sources such as batteries. These components are carefully designed to fit within the constraints of the implantable device and to withstand the harsh environment inside the body.

The software components include the algorithms that process the data collected by the sensors, and the communication protocols that enable the device to transmit data to external devices. These algorithms must be

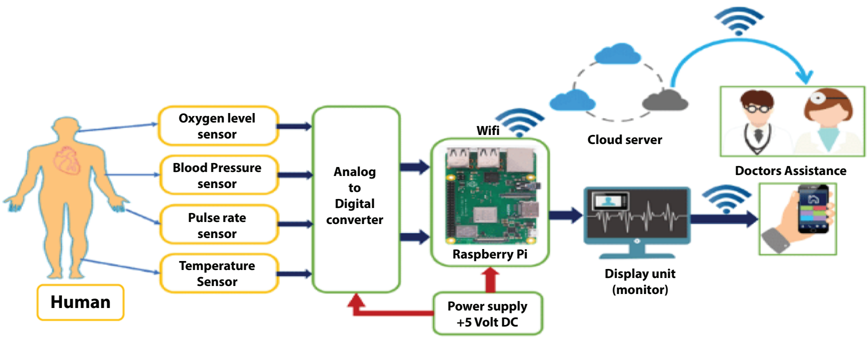

Figure 1.1 Technical framework of IoT-based implant devices in humans for therapeutic reasons.

optimized for low power consumption and high efficiency, as the devices are often powered by small batteries that must last for years. In addition, the software must be highly secure to prevent unauthorized access to the device and the sensitive data it collects shows the evidence of Technical framework of IoT-based implant devices in humans for therapeutic reasons.

Advances in microelectronics, wireless communication, and biomedical engineering have made it possible to develop increasingly sophisticated IoT-based implantable devices. These devices have the potential to revolutionize healthcare by enabling real-time monitoring of vital signs, drug delivery, and other critical parameters. The technology behind IoT-based implants is constantly evolving, driven by the need for smaller, more powerful, and more reliable devices that can provide accurate and timely information to healthcare professionals.

Some of IoT-based implant devices that are currently being developed or used for therapeutic purposes in humans.

This chapter outlines the significance of IoT-based implant devices for therapeutic purposes in both humans and animals. It covers various aspects related to these devices, including current developments, potential improvements, and future directions.

1.2 Application of IoT in Implantable Insulin Pumps

An insulin pump is a medical device that is used to deliver insulin to individuals with diabetes. This device replaces the need for multiple daily injections of insulin by delivering a continuous flow of insulin into the body. In recent years, implantable insulin pumps have gained popularity due to their ability to provide insulin therapy without the need for external tubing or devices. IoT technology is revolutionizing the field of healthcare, particularly in devices like implantable insulin pumps. These pumps, surgically implanted under the skin, continuously deliver insulin to manage diabetes IoT components enhance their functionality in the following ways:

Remote Monitoring and Adjustment: IoT-enabled insulin pumps allow healthcare professionals to remotely monitor patients' glucose levels and adjust insulin dosages in real-time. This remote connectivity reduces the need for frequent clinic visits and enables timely interventions.

Wireless Connectivity: The integration of wireless communication modules like Bluetooth or cellular connectivity facilitates seamless data transmission from the pump to external devices or cloud platforms. This connectivity ensures that patients and healthcare providers have access to critical health data.

Data Analytics and Insights: IoT-enabled pumps collect a wealth of data, including insulin delivery rates and glucose levels. Advanced analytics algorithms process this data to generate insights, enabling healthcare providers to make informed decisions about treatment adjustments.

1.3 Application of IoT in Implantable Heart Monitors

As shown in Figure 1.2, an implantable heart monitor device that is inserted beneath the skin of a patient's chest. The device is small and compact, roughly the size of a pacemaker, and is connected to leads that are implanted into the heart. The leads monitor the electrical activity of the

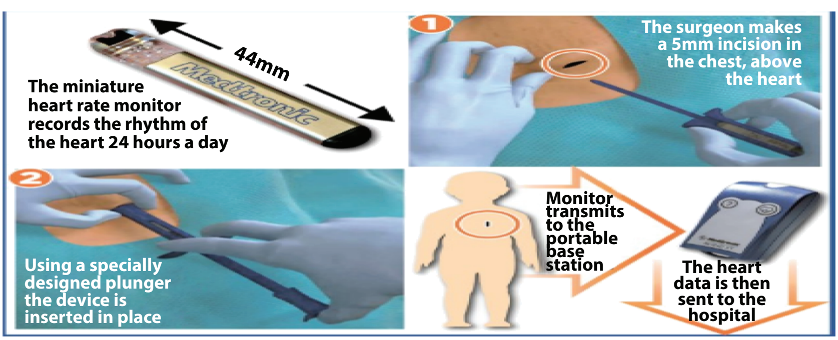

Figure 1.2 Implantable heart monitors.

heart and send this information to the device. An implantable heart monitor is a small device that is placed inside a patient's chest to continuously monitor their heart rhythm and detect any abnormalities. These devices are typically used in patients who have a history of heart disease or other cardiovascular issues, as they provide continuous monitoring of the heart's electrical activity and can help detect potential issues early on. Implantable heart monitors, also known as cardiac implants or pacemakers, are life-saving devices used to monitor and regulate heart rhythms [4].

The application of IoT in these devices brings several benefits:

Remote Monitoring and Alerts: IoT-enabled heart monitors can transmit real-time heart rhythm data to healthcare providers. This remote monitoring allows for early detection of irregularities, enabling prompt medical intervention.

Alerts and Notifications: When abnormal heart rhythms are detected, IoT-enabled monitors can automatically send alerts to both patients and healthcare providers. This rapid communication ensures timely responses to critical situations.

Data-driven Insights: IoT components collect data on heart rhythm patterns over time. Analyzing this data helps healthcare professionals identify trends, triggers, and potential risk factors, leading to more personalized treatment plans.

1.4 Application of IoT in Implantable Nerve Stimulators

Implantable nerve stimulators are devices that use electrical impulses to stimulate the nerves in the body. These devices are typically used to treat chronic pain or other conditions that are resistant to traditional treatments. IoT integration offers the following advantages:

Remote Control and Adjustment: IoT-enabled nerve stimulators allow patients to adjust stimulation settings within prescribed limits. This remote control enhances patient comfort and minimizes the need for in-person adjustments.

Data-driven Optimization: The continuous collection of stimulation data enables healthcare providers to optimize therapy settings for individual patients. This data-driven approach enhances treatment outcomes and patient satisfaction.

1.5 Application of IoT in Implantable Drug Delivery Systems

Implantable drug delivery systems are a type of medical device that are designed to deliver medication directly into the body over an extended period of time. These devices have revolutionized the way we treat many chronic conditions, providing a more targeted and consistent drug delivery than traditional methods such as pills or injections. Implantable drug delivery systems have a wide range of applications, from treating chronic pain to managing diabetes, cancer, and other diseases. Incorporating IoT components enhances their effectiveness:

Dosing Personalization: IoT-enabled drug delivery systems can adapt dosing regimens based on real-time physiological data. This personalized approach ensures optimal drug delivery and therapeutic outcomes.

Adherence Monitoring: IoT technology allows healthcare providers to monitor patients' medication adherence. This ensures that patients receive the prescribed medications on time, leading to improved treatment effectiveness.

1.6 Application of IoT in Implantable Brain-Computer Interfaces

Implantable Brain-Computer Interfaces (BCIs) are devices that enable direct communication between the human brain and a computer. They are designed to help people who have lost motor function due to neurological injuries or disorders, such as injuries in spinal cord, stroke, or amyotrophic lateral sclerosis (ALS).

Implantable brain-computer interfaces establish direct communication pathways between the brain and external devices. The incorporation of IoT technology expands their capabilities:

Real-time Feedback: IoT-enabled brain-computer interfaces can provide real-time feedback to users based on brain activity. This feedback can be used to control external devices, enhancing user interaction and quality of life.

1.7 Application of IoT in Implantable Biosensors

Implantable Micro-Electro-Mechanical Systems (MEMS) are small devices that combine mechanical, electrical, and computational components to enable a wide range of biomedical applications. MEMS devices are typically smaller than a few millimeters and are implanted into the body to monitor or modulate various physiological processes. They are made up of microfabricated components that can sense, measure, and respond to physical and chemical stimuli.

Implantable biosensors are used to continuously monitor various physiological parameters within the body. Integrating IoT components enhances their functionality:

Continuous Monitoring: IoT-enabled biosensors can transmit real-time data on parameters like glucose levels, oxygen saturation, or pH. This continuous monitoring provides healthcare professionals with timely insights for treatment adjustments [6].

In conclusion, IoT technology is revolutionizing the healthcare landscape by enhancing the capabilities of implantable medical devices. From remote monitoring and personalized treatment to real-time insights and improved patient outcomes, the application of IoT is transforming the way these devices function and contribute to patient care.

1.8 IoT Revolutionizing Healthcare Devices: A Comparative Analysis of IoT-Based Implants vs. Conventional Medical Devices

The advent of IoT technology has introduced a new dimension to medical implants, revolutionizing the way we perceive healthcare devices. A compelling comparison between IoT-based implanted devices and conventional non-IoT devices highlights the transformative impact of IoT on medical implants [7].

Connectivity and Remote Monitoring:
IoT-Implanted Devices: IoT-based implants enable seamless wireless connectivity, allowing real-time data transmission to remote platforms. This enables healthcare providers to monitor patients' conditions and device functionality from a distance.

Conventional Devices: Non-IoT medical implants lack remote monitoring capabilities. Monitoring often requires in-person visits to healthcare facilities, limiting timely intervention and patient convenience.

Data Analysis and Insights:
IoT-Implanted Devices: Data collected by IoT implants can be analyzed for trends, patterns, and anomalies. These insights aid in personalized treatment plans and proactive healthcare management.
Conventional Devices: Conventional implants lack the ability to provide data-driven insights, often resulting in delayed reactions to medical conditions.

Real-time Alerts and Notifications:
IoT-Implanted Devices: IoT implants can generate real-time alerts and notifications to both patients and healthcare providers in case of critical events, ensuring timely medical attention.
Conventional Devices: Without IoT connectivity, conventional implants cannot provide immediate alerts, potentially leading to missed opportunities for urgent medical care.

Personalized Treatment:
IoT-Implanted Devices: IoT-enabled implants allow for personalized adjustments in treatment plans based on real-time data, optimizing patient outcomes.
Conventional Devices: Conventional implants rely on fixed settings, lacking the flexibility to adapt to changing patient needs.

User Engagement and Empowerment:
IoT-Implanted Devices: IoT devices engage patients by offering them access to their health data through mobile apps, fostering better understanding and active participation in their treatment journey.
Conventional Devices: Non-IoT implants may not provide patients with insights into their health data, limiting their involvement in healthcare decisions.

Predictive Maintenance:
IoT-Implanted Devices: IoT technology facilitates predictive maintenance of implants, identifying potential malfunctions and minimizing device failure risks.
Conventional Devices: Conventional implants may fail without warning, leading to unexpected complications for patients.

Timely Healthcare Interventions:
IoT-Implanted Devices: IoT implants enable early detection of anomalies, allowing healthcare providers to intervene promptly and prevent worsening conditions.
Conventional Devices: Conventional implants may not provide early indicators of problems, resulting in delayed medical interventions.

Long-term Monitoring and Historical Data:
IoT-Implanted Devices: IoT technology enables long-term data storage and analysis, offering a comprehensive view of patients' health history and trends.
Conventional Devices: Non-IoT implants lack the ability to provide a holistic view of patient health over time.

While IoT-based implanted devices offer unprecedented benefits, challenges such as power consumption, data security, and regulatory compliance must be carefully addressed. The comparison underscores the transformative potential of IoT in reshaping healthcare through continuous monitoring, real-time data analysis, and improved patient engagement. IoT components used in implantable devices for humans, along with examples and their working principles [8]:

Wireless Communication Module:
Example: Bluetooth Low Energy (BLE), Cellular Modem
Working: The wireless communication module enables the implantable device to establish a connection with external devices or networks. It can transmit data to remote servers, healthcare providers, or the patient's smartphone. This real-time communication allows for continuous monitoring and remote adjustments.

Sensors:
Example: Accelerometers, Temperature Sensors
Working: Sensors embedded in the implantable device collect various physiological data. For instance, accelerometers can measure movement or activity levels, while temperature sensors can monitor body temperature. These sensors convert physical data into digital information that can be processed and transmitted for analysis.

Microcontroller or Processor:
Example: ARM Cortex-M series microcontroller
Working: The microcontroller acts as the brain of the implantable device. It processes data from sensors, manages power usage, and controls data

transmission. It can execute algorithms for signal processing, data compression, or encryption, depending on the device's purpose.

Memory:
Example: Flash memory
Working: Memory storage is crucial for storing collected data, device settings, and firmware updates. It ensures that data is retained even if there is a temporary loss of communication. Healthcare providers can retrieve historical data for analysis.

Power Management System:
Example: Lithium-ion battery, Energy Harvesting
Working: The power management system is responsible for providing a stable and long-lasting power source. Implantable devices may use rechargeable batteries or energy harvesting techniques to harness energy from the body's movements or other sources, extending the device's lifespan.

Encryption and Security Features:
Example: Advanced Encryption Standard (AES), Secure Boot
Working: Security features are crucial to protect patient data and the device itself. Encryption methods like AES secure data during transmission, while secure boot processes ensure that only trusted software runs on the device, preventing unauthorized access.

External Communication Interface:
Example: USB, Proprietary Docking Station
Working: In some cases, external communication interfaces facilitate interactions between the implantable device and external devices or healthcare providers during check-ups or for device configuration, data retrieval, or firmware updates.

Biocompatible Materials:
Example: Titanium, Medical-grade Polymers
Working: Implantable devices are constructed using biocompatible materials to minimize the risk of tissue rejection or adverse reactions. These materials ensure the device can function safely within the human body.

Together, these IoT components enable implantable devices to collect, process, and transmit vital health data, allowing for remote monitoring, timely interventions, and improved patient care. They are pivotal in advancing the field of medical technology and enhancing the quality of life for individuals with various medical conditions.

1.9 Challenges in Therapeutic Implant Devices for Humans and Animals

Let us explore the typical challenges present in implant devices in animals/ humans for therapeutic.

IoT-based implant devices in animals/humans for therapeutic reasons present unique security challenges, as they are designed to be implanted in the body and can potentially be accessed remotely by unauthorized individuals. Here are some of the main security challenges associated with these devices [3]:

Device hacking: IoT-based implant devices are vulnerable to hacking, which could lead to unauthorized access to patient data, manipulation of device settings, or even physical harm to the patient. Hackers could exploit vulnerabilities in the device's firmware or software to gain access to the device.
Data privacy: IoT-based implant devices collect and transmit sensitive patient data, such as medical history, biometric data, and other personal information. If this data falls into the wrong hands, it could be used for identity theft, fraud, or other malicious purposes.
Physical security: Implantable devices are physically attached to the body and can be difficult to access or replace if they are compromised. Patients must be vigilant about protecting their devices from theft or tampering.
Regulatory compliance: IoT-based implant devices must comply with various regulations and standards, such as HIPAA and FDA regulations. Failure to comply with these regulations could result in legal and financial penalties.

To address these security challenges, device manufacturers, healthcare providers, and regulatory bodies must work together to implement appropriate security measures. These measures may include:

- Strong authentication and encryption mechanisms to secure device communications and prevent unauthorized access.
- Regular software updates and security patches to address vulnerabilities and improve device security.
- Physical security measures, such as tamper-evident seals and anti-theft mechanisms, to protect the device from physical tampering.

- Patient education and training to raise awareness of device security risks and best practices for device management.
- Compliance with relevant regulations and standards to ensure that devices meet minimum security requirements.

Ensuring data security and cryptography for implanted materials is a rapidly evolving area, with several recent trends emerging to address the unique security challenges of these devices [5].

Here are some of the key trends:
Block chain technology: Block chain technology provides a secure and decentralized way to store and manage patient data. By using a block chain-based system, data can be securely stored, verified, and accessed by authorized parties without the need for a central authority.
Advanced cryptography: Advanced encryption techniques such as homomorphic encryption, zero-knowledge proofs, and multi-party computation are being developed and applied to implanted materials. These techniques allow for secure computation and data sharing without compromising patient privacy.
Cybersecurity regulations: Governments and regulatory bodies are increasingly implementing regulations and standards to ensure the cybersecurity of implanted materials. For example, the U.S. FDA has issued guidelines for medical device manufacturers to help ensure the security of medical devices, including implanted materials.
Machine learning and AI: Machine learning and AI can be used to detect and prevent cyber-attacks on implanted materials. By analyzing huge amounts of dataset, these technologies ML and AI can identify patterns which are irregular and unnatural that may indicate a security breach.
Physical security measures: In addition to digital security measures, physical security measures are also being developed to protect implanted materials. For example, researchers are developing nanoscale structures that can be embedded in materials to provide physical security and prevent tampering.

Overall, ensuring data security and cryptography for implanted materials is a complex and rapidly evolving field, with many promising technologies and strategies being developed to address the unique security challenges of these devices. By staying up-to-date with the latest trends and developments, researchers and practitioners can help ensure the safety and security of these devices for patients.