Chapter 7

Edge Computing and Smart Data Processing in Ultrasound-Based Manufacturing

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ABSTRACT

Ultrasound-based manufacturing has emerged as a transformative technology, enabling precise, non-invasive, and efficient production processes across various industries such as automotive, aerospace, biomedical, and electronics. However, the real-time data generated by ultrasonic sensors presents significant challenges in terms of latency, bandwidth, and computational load when processed through traditional cloud-based systems. This chapter explores the integration of edge computing into ultrasound-based manufacturing, focusing on smart data processing strategies that bring computation closer to the data source. Edge devices are leveraged to perform initial data filtering, feature extraction, anomaly detection, and decision-making with minimal latency. We examine how this localized processing enhances the responsiveness, reliability, and security of ultrasound applications. Additionally, we delve into use cases, architectural frameworks, and future trends, including AI at the edge and federated learning. This convergence of edge computing and ultrasound-based manufacturing paves the way for intelligent, scalable, and sustainable industrial systems.

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INTRODUCTION

In the evolving landscape of advanced manufacturing, the integration of intelligent systems is playing a vital role in transforming traditional processes into more efficient, autonomous, and scalable operations. Among these technological advancements, ultrasound-based manufacturing has gained significant traction due to its non-invasive nature, precision, and adaptability across multiple domains. From additive manufacturing to welding and cutting, ultrasonic techniques offer high-frequency mechanical vibrations that enhance accuracy and reduce material waste, ultimately leading to improved product quality and operational efficiency.

Despite these advantages, the growing complexity and volume of data generated by ultrasonic sensors present new challenges for data acquisition, processing, and real-time decision-making. As manufacturing systems increasingly rely on high-frequency, time-sensitive data, the conventional approach of transmitting this information to a centralized cloud for processing becomes inadequate. Issues such as latency, bandwidth constraints, data privacy, and system reliability create bottlenecks that can impede performance and limit the scalability of ultrasound-based solutions.

This is where edge computing emerges as a game-changer. Edge computing refers to the decentralized model of computing where data processing and analytics are performed at or near the data source—such as the ultrasonic device or embedded sensor node—rather than relying solely on centralized cloud infrastructure. By enabling localized, real-time computation, edge computing significantly reduces the latency associated with data transfer, alleviates the burden on network bandwidth, and enhances the responsiveness and reliability of manufacturing systems.

In the context of smart manufacturing, edge computing facilitates smart data processing, which refers to the use of intelligent algorithms and decision-making mechanisms to analyze and act upon sensor data in real time. In ultrasound-based applications, this means enabling systems to detect anomalies, monitor quality, optimize processes, and make predictive adjustments without the need for continuous human intervention or remote computation. Such capabilities are vital for implementing Industry 4.0 practices, where the emphasis is on cyber-physical systems, automation, and interconnected manufacturing environments.

The convergence of edge computing and ultrasound-based manufacturing introduces a new dimension of possibilities for real-time industrial intelligence. For instance, in ultrasonic additive manufacturing (UAM), where layers of metal are bonded using high-frequency ultrasonic vibrations, real-time monitoring of bonding quality and material behavior is essential. With edge-enabled smart sensors, deviations in the bonding process can be detected and corrected immediately, reducing defects and ensuring consistent output. Similarly, in ultrasonic welding, edge systems can