A Review: Integration of Computational Material Science with AIoT for Enhanced IoT Applications

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Abstract

The rapid growth of the Internet of Things (IoT) has necessitated the development of systems capable of processing data efficiently and in real-time in computation material science. Traditionally, cloud computing has been used to manage and analyze the vast amounts of data generated by IoT devices to store and analyze observed data (as results of the materials) which further use as survey data application. However, cloud-based solutions often face challenges related to latency, bandwidth consumption, periodically survey, comparison with standard data and energy inefficiency, especially in resource-constrained environments. To address these challenges, edge computing has emerged as a promising solution, bringing computation closer to the data source. The integration of Artificial Intelligence (AI) agents in edge computing through microcontrollers can provide enhanced decision-making capabilities in IoT applications, offering both performance and energy efficiency. This review paper explores the advanced implementation of AI agents in edge computing using microcontrollers for IoT applications for material science as computing agent for data storage, comparison, analyzing and many more, with a specific emphasis on material science applications, highlighting the benefits and challenges of deploying lightweight AI models on resource-constrained devices.

Keywords: AI Agents, Edge Computing, Microcontrollers, IoT Applications, Computation material science, Data Processing.
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Introduction

Despite the potential advantages of microcontrollers in edge computing, their limited processing power and memory make the integration of AI models particularly challenging [1]. However, advancements in lightweight machine learning algorithms and microcontroller architectures have made it increasingly feasible to deploy AI agents directly on edge devices. This paper aims to bridge the existing gap by exploring methodologies for implementing AI on microcontrollers within IoT ecosystems, particularly for material science applications [2,3]. The research focuses on key areas such as energy efficiency, latency reduction, and real-time decision-making in the context of material science, examining various use cases such as predictive maintenance of smart materials, real-time monitoring of material properties, and the development of adaptive materials in smart agriculture, healthcare, and smart cities [4,5]. The study also presents a comprehensive analysis of current tools, frameworks, and techniques for deploying AI on microcontrollers, providing recommendations for future advancements in this field [6-8].

This study highlights the key contributions of microcontroller-based edge computing in enhancing the performance and scalability of IoT applications related to material science [9]. By developing a framework for deploying AI agents on microcontrollers, this paper not only aims to address existing challenges but also lays the groundwork for further research and development in this domain [10]. The methodology used in this study integrates both qualitative and quantitative approaches to evaluate the impact of AI on microcontroller-based edge computing, with a focus on improving the autonomy, efficiency, and sustainability of IoT devices in material science applications [11,12].

Literature Review

Recent studies have investigated the integration of machine learning (AI) with the Internet of Things (IoT), specifically within the realm of computational material research [13]. The integration of edge computing with artificial intelligence has several benefits, such as less reliance on cloud infrastructure, decreased latency, and enhanced energy efficiency [14]. The implementation of AI on resource-limited devices, including microcontrollers that remains underexplored, resulting in an absence of feasible methodologies for integrating artificial intelligence at the boundary in materials research applications [15].

An essential obstacle to computational materials research is the computational limitation of microcontrollers [16]. AI models, especially deep learning techniques, sometimes need considerable processing resources, making their deployment on microcontrollers difficult [17]. Liu et al. (2020) illustrated the use of lightweight AI models on edge devices, including microcontrollers, emphasizing real-time sensor data processing. Their research emphasized AI's capacity to minimize data transmission to the cloud and facilitate expedited decision-making in material science domains [18].

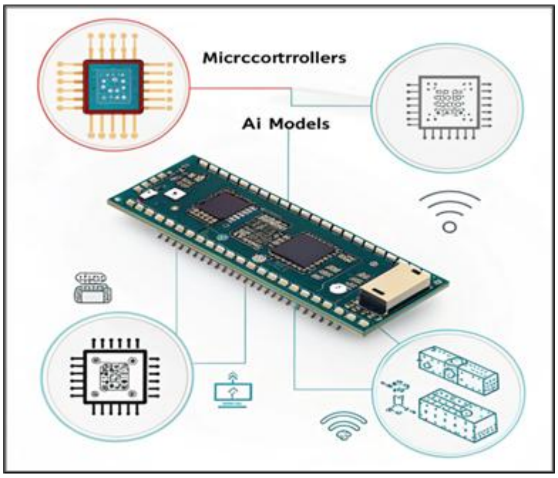

Figure 1: Comparison of latency between edge and cloud computing for IoT applications.

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The Comparison of latency between edge and cloud computing for IoT applications is depicted in Figure 1. Internet of Things (IoT) applications rely heavily on latency, which affects the efficiency and responsiveness of the system. High computational power and scalable storage are advantages of cloud computing, which processes data in centralized servers. However, due to long-distance data transmission, cloud computing experiences higher latency, ranging from 50 ms to several seconds. There may be delays in real-time applications and higher bandwidth consumption because of how dependent it is on internet connectivity. As a counterexample, edge computing minimizes bandwidth usage, improves real-time decision-making, and significantly reduces latency (1ms to 20ms) by processing data closer to the source. Autonomous vehicles, industrial automation, and healthcare monitoring are latency-sensitive scenarios that are best handled by edge computing, whereas cloud computing is better suited for storage-intensive applications and large-scale data analytics. When it comes to real-time response, network efficiency, and reliability, edge computing trumps cloud computing, according to graphical comparisons of latency. By dividing up computations between edge nodes and the cloud, hybrid approaches like fog computing are able to reap the benefits of both. Processing speed, network reliance, and data handling efficiency are just a few of the aspects that should be considered when deciding between cloud computing and edge computing for an Internet of Things application.

A further problem in computerized science of materials is the absence of AI frameworks tailored for microcontrollers [22]. Despite the development of frameworks such as Tensor Flow Lite, and Edge Impulse for resource-constrained contexts, they remain in a state of evolution and may not be applicable to all material-related applications. The need for prompt execution exacerbates the difficulties of deploying AI on microcontrollers, since several AI models demand substantial computational power as well as memory bandwidth for maximum efficacy. Furthermore, there is an absence of standardized approaches and protocols to facilitate interaction between microcontroller-based devices inside an edge computing framework [23]. This constrains the capacity to create scalable and extensible IoT systems dependent on edge-based AI processing in materials science.

Gap Analysis

The integration of AI agents with microcontrollers within computational materials science faces several substantial challenges. The main issue is the computational limitation of microcontrollers, which sometimes do not possess the requisite computing power to implement intricate AI models [24]. Notwithstanding the advancement of many lightweight models, several options continue to demand greater power than microcontrollers that can provide, resulting in performance trade-offs in material science applications.

Methodology

This research utilizes a mixed-methods approach, integrating qualitative and quantitative methodologies to evaluate the feasibility and effectiveness of AI agents functioning on microcontrollers that for utilization in cognitive materials science, especially within IoT-based systems. The key components of the methodology are as follows:

The study will use artificial intelligence models on microcontrollers that within materials science, concentrating on intelligent production and environmental monitoring. These domains are chosen for their data-centric characteristics and the need for instantaneous analysis and decision-making, essential for enhancing material qualities and processes [25]. Microcontrollers, namely ARM Cortex-M4 and the ESP32 micro will be used for the deployment of AI agents. These microcontrollers have sufficient processing capability for lightweight algorithms based on AI and are often used in IoT applications [26]. Lite implementations of Tensor Flow for Arduino boards and Edge Impulse will be used to create and implement AI models specifically designed for materials research applications [27].

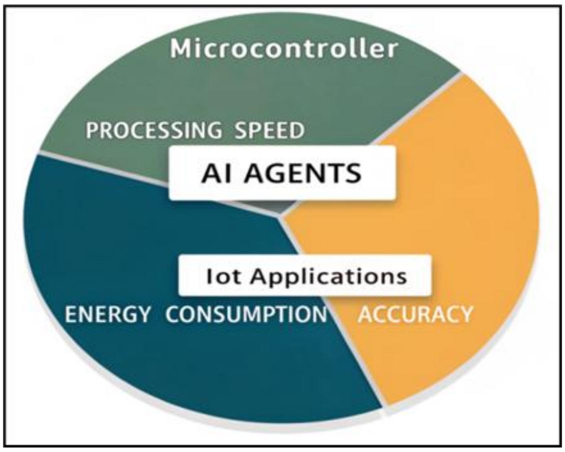

Figure 2: AI gents and IoT applications.

Technology and Gathering Information: Real-time sensor data, including humidity, temperature, pressure, and substance composition, will be collected from IoT devices inside the specified materials science settings. The data will be pre-processed and input into compact AI models operating on the microcontrollers [28]. The models will thereafter be assessed for their capacity to effectively analyse data and facilitate decision-making in the optimization and monitoring of material properties. The efficacy of the artificially intelligent agents will be evaluated by critical parameters such as accuracy, latency, and consumption of energy. Statistical techniques will be used to examine the performance disparities across edge computer systems and platforms running on the cloud [29]. Furthermore, qualitative data will be gathered via field observations to assess the practical usability and efficacy of microcontroller-based artificial intelligence systems in material science settings.

The research design is meticulously organized to guarantee repeatability by providing complete requirements for the hardware, software setups, and code versions used. This will allow other researchers to reproduce the work and verify the results, assuring wider relevance in computerized materials science [30].

Conclusion

The incorporation of AI agents in computing at the edge, especially via microcontrollers, offers a viable resolution to the difficulties encountered by conventional stored in the cloud Internet of Things (IoT) systems in computerized materials science. By analysing information at the edge, near its origin, AI agents may minimize latency, optimize bandwidth, and enhance energy efficiency. This research has shown that microcontrollers as despite their constrained processing capabilities, may be efficiently used for real-time, compact AI projects in materials research IoT settings.

This study underscores the need of enhancing AI algorithms and architectures specifically designed for microcontroller-based edge computing in materials science. Despite ongoing issues with computing limitations and real-time processing, progress in AI model compression as well, pruning, and quantization is facilitating more efficient implementations. Moreover, applications in domains such as intelligent manufacturing, material property assessment, and environmental monitoring demonstrate that microcontroller-based artificially intelligent agents may improve decision-making, resulting in more self-sufficient, responsive, and effective IoT systems within materials science.

The research highlights the revolutionary capabilities of microcontroller-based artificial intelligent agents in cuttingedge computing for materials research applications. This study establishes a foundation for future research by identifying deficiencies in the existing literature and suggesting methodologies for the integration of AI into microcontrollers. The incorporation of AI agents into IoT systems within materials science may catalyse innovation across several industries, enhancing sustainability, effectiveness, and overall system functionality.

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