Benefits And Challenges of Edge Computing For Real-Time Data Processing in Manufacturing And Autonomous Vehicles Industries

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- Month 2024 –

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ACKNOWLEDGEMENT

The completion of this research would not have been possible without the invaluable advice and support of my advisors, to whom I am eternally grateful. Their support and constructive criticism have been invaluable in helping me develop as a researcher and have a profound impact on my work. I am incredibly grateful to my family for their constant encouragement and empathy during this ordeal. I was able to overcome obstacles because of the support and encouragement I received from their love and faith in me. In addition, I want to express my deepest gratitude to my friends, whose friendship and encouragement have been priceless. Their unfailing support and tolerance have been an inspiration to me. Without the help of these extraordinary people, this study would not have been feasible; for their generosity, I am eternally grateful.

ABSTRACT

Edge Computing, an increasingly advanced technology in the modern world, has the capability to meet the growing need for sophisticated production and transportation worldwide. This research investigates the benefits and challenges associated with the adoption of edge computing for real-time data processing in the manufacturing and autonomous vehicle industries. The study focuses on exploring the factors influencing the adoption of edge computing technologies and their subsequent impact on these industries. A survey was conducted with a sample size of 1,011 participants, providing a comprehensive dataset for analysis. The data collected were analyzed using Structural Equation Modeling-Partial Least Squares to determine the relative impact of various factors on the adoption of edge computing. The analysis revealed that among the factors studied, relative advantage significantly and positively impacts the adoption of edge computing. Despite the potential benefits, the study also identifies several challenges that could hinder the widespread adoption of edge computing. These include the integration of edge computing technologies with existing systems, the need for technical expertise, and the substantial initial investment required. The findings of this research provide valuable insights for industry stakeholders, policymakers, and technology developers, offering a nuanced understanding of the role of edge computing in advancing the capabilities of the manufacturing and autonomous vehicle industries.

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Chapter 1: Introduction

1.1 Background and Context

The development of Industry 4.0 and the spread of the Internet of Things (IoT) have fundamentally changed the scene of data processing in the sectors of manufacturing and autonomous cars. Real-time data processing is becoming more and more important for these industries to guarantee operating efficiency, safety, and adaptation in dynamic contexts (Kubiak et al., 2022). Although strong, traditional cloud-based computing often fails to meet the strict latency requirements and the necessity for localized data processing these sectors need. Edge computing has therefore become a fundamental technology as it provides a distributed method allowing data processing at the source of data creation. Particularly in situations requiring real-time decision-making, this change is essential for systems where milliseconds may determine whether success or failure results.

Adoption of edge computing in manufacturing lets data generated by sensors and devices on the production floor be immediately processed (Nain et al., 2022). This capacity not only lowers latency but also improves the capacity to continuously monitor and manage industrial operations, thus improving the quality of products, lowering of downtime, and raising of general efficiency. Moreover, edge computing minimizes unplanned failures and maximizes maintenance schedules by allowing real-time analysis of machine data, hence supporting predictive maintenance.

In the field of autonomous cars, edge computing is also very important for handling the enormous volumes of data produced by many onboard sensors like radar systems, LiDAR, and cameras (Sandu & Susnea, 2021). To properly and quickly negotiate difficult settings, these vehicles need fast processing and decision-making. Cloud computing's latency and bandwidth limitations render it inappropriate for such uses, where even little delays might have disastrous results (Hassan et al., 2018). Autonomous cars may improve their dependability and responsiveness by processing data at the edge therefore enabling real-time choices with less dependence on cloud infrastructure.

Edge computing offers numerous difficulties even if it has benefits for several sectors. Edge infrastructure deployment calls both large hardware, software, and network resource investments (Abbas et al., 2017). Furthermore, introducing complexity in data management, security, and interoperability are the heterogeneous character of edge devices and the scattered character of edge networks (Talebkhah et al., 2020). Moreover, a major issue is making sure edge computing solutions are scalable enough to handle the rising data volume produced by IoT devices and the ever more complicated industrial and vehicle systems need.

1.2 Fundamentals of Edge Computing

Edge computing is the set of technologies that allow processing to happen at the network's periphery, on data that is either downstream for cloud services or upstream for Internet of Things services. Any computer or network resources that are used between data sources and cloud data centers are referred to as "Edge" in this context (Wang et al., 2020). The smartphone acts as a bridge between the user's physical devices and the cloud, the smart home gateway as an intermediary between the user's physical house and the cloud, and the micro data center (MDC) and cloudlet as the last link between the user's mobile device and the cloud (Satyanarayanan et al., 2009). Computing, according to the theory of "Edge computing," should take place close to where the data is stored. While both terms may be used interchangeably, in our opinion, Fog computing is more concerned with the underlying infrastructure while Edge computing is more focused on the Things side (Group, 2016). We believe that Edge computing has the potential to significantly influence our society, comparable to the influence of Cloud computing. The Edge computing two-way streams are shown in Fig. 1 (Shi et al., 2016). In the edge computing model, objects serve as both data consumers and data creators.

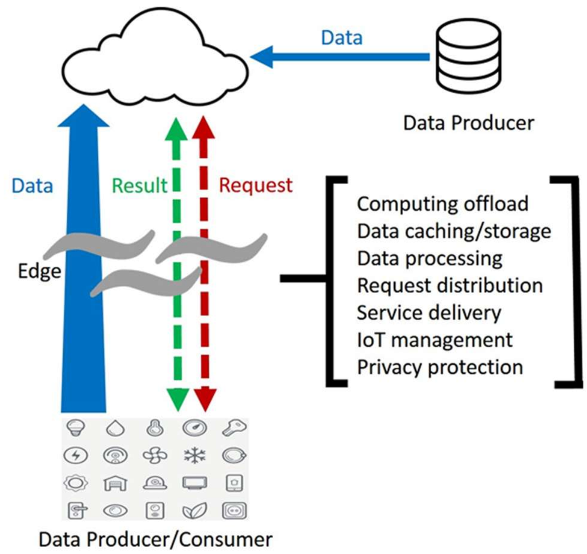

Fig 1. Paradigm of edge computing (Shi et al., 2016).

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In addition to receiving data and services from the cloud, entities at the edge may also do computations on behalf of the cloud. Computing offloading, data storage, caching, processing, and distribution of cloud-to-user request and delivery services are all within the edge's capabilities (Kaur & Batth, 2021). When it comes to those network tasks, the edge itself has to be well-designed to effectively satisfy service requirements like privacy protection, security, and dependability.

1.3 Cloud Computing and Edge Computing

Cloud computing has become a cornerstone of modern information technology, providing a scalable, on-demand network of resources that enable the storage, processing, and management of vast datasets. Fundamentally, cloud computing operates on the principle of resource virtualization, where computational power, storage, and network resources are abstracted from physical hardware and made accessible over the internet (Krishnasamy et al., 2020). This model offers unparalleled flexibility and scalability, allowing organizations to dynamically allocate resources based on demand, thereby optimizing costs and enhancing efficiency. Cloud computing has three service models: Infrastructure as a Service (IaaS), which provides virtualized computing resources; Platform as a Service (PaaS), which provides a platform for developing and deploying applications; and Software as a Service (SaaS), which delivers software applications over the internet (Liang et al., 2024).

Cloud and edge computing differ mostly in data processing location and speed. Edge computing computes near the data source, usually at the network's edge or on the device, unlike cloud computing, which centralizes data processing in faraway data centers (Ekatpure, 2023). Edge computing is appropriate for real-time applications like autonomous cars and industrial automation because it is close to data sources and reduces latency (Asim et al., 2020).

Moreover, edge computing alleviates the bandwidth burden on the cloud by processing data locally and only sending necessary information to the cloud for further analysis or storage (Pan & McElhannon, 2017). In contrast, cloud computing, despite its robust processing capabilities, can suffer from latency issues and potential bottlenecks due to the data's journey to and from centralized servers. Thus, while cloud computing remains indispensable for large-scale data processing and storage, edge computing is increasingly recognized as a complementary approach, particularly suited for time-sensitive and location-specific tasks (Cao et al., 2021).

1.4 Thesis Outline

This thesis explores the benefits and challenges of edge computing for real-time data processing, particularly within the manufacturing and autonomous vehicle industries. The study begins with an introduction to the background and fundamentals of edge computing, followed by a comprehensive literature review that traces the history, current advancements, and existing research gaps in the field. The research methodology chapter details the study’s design, population, data collection methods, and ethical considerations. The subsequent chapter presents the development of the research model and hypotheses, which are later tested in the findings and analysis section. Two dedicated chapters examine the specific applications, benefits, and challenges of edge computing in manufacturing and autonomous vehicles. The study concludes by summarizing the key findings and outlining the future challenges that need to be addressed for the broader adoption of edge computing in these critical sectors.