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Industrial Edge Computing: Architecture, Challenges, Applications

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Abstract **–**Edge computing is the deployment of network operations and data-handling activities toward more solitary sources of data collecting or storage. Industrial edge computing, which includes industrial applications, describes the method of controlling data-handling operations using distinct data sources, such as smart edge devices. As a result, whether collecting, processing, or evaluating data in smart factories, IIoT devices and smart equipment do not need to contact centralised cloud platforms. Information can also be sent to the cloud for additional analysis or integration into a larger system, depending on how important the data analysis performed at the edge is. Industrial edge computing is a term used to describe a distributed platform that combines communication, processing, and storage capabilities to run real-time applications that may be accessed directly from the cloud. The Industrial Internet of Things (IIoT) revolution has raised demands for flexible connectivity, real-time control, data optimization, intelligent applications, security, and privacy protection. Edge computing nodes serve as intelligent gateways for assets, services, and systems, bridging the gap between the real and digital worlds.
Key Points : Industrial Edge Computing, IIoT, Edge Computing nodes(ECN), Edge computing, Industrial clouds.

1. INTRODUCTION

Edge computing provides multiple use cases that vendors and service providers can explore to increase revenue generation across diverse industries. The creation of wearables with low-latency processing is a potential source of revenue for hardware vendors. The first step in creating a deployment plan is to determine the use case or particular process you want to improve. The definition then gives you the starting point you need to find and select providers offering cutting-edge solutions that suit your particular requirements and can be incorporated into current production systems. End-users of edge computing will be guaranteed to benefit from the numerous advantages it offers with a deployment strategy that takes into account both current and future systems.

Edge computing uses sensing, communication, and data processing technologies to interconnect a large number of components, achieving many advances in diverse areas, which have strong performance impacts on edge computing.

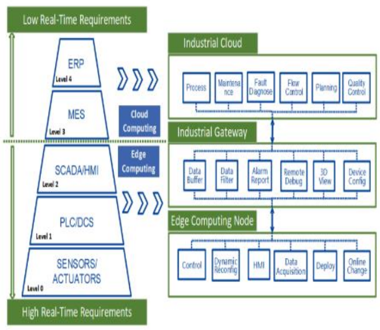

Fig 1: The ISA-95 Reference Architecture Mapping to Industrial Cloud and Edge

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2. ARCHITECTURE

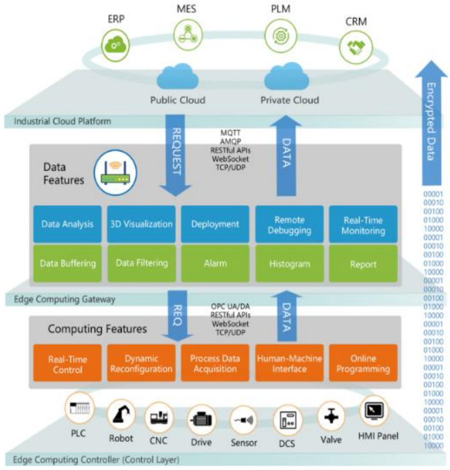

Fig 2: The Industrial Edge Computing Reference Model

Three layers make up the architecture in the Industrial Edge Computing Reference Model. The industrial cloud platforms are the top layer, offering a variety of applications for design, manufacture, management, and maintenance. To lower implementation and maintenance costs, legacy ERP, MES, Product Life-Cycle Management (PLM), and Customer Relationship Management (CRM) systems could be moved to industrial clouds. Real-time data gathered from edge computing devices could also improve cutting-edge industrial cloud applications including device operation monitoring, supply chain analysis, and energy usage optimization. Even third parties could offer these services, which would function on a private cloud as opposed to a public one. The industrial edge gateway, which is part of the middle layer, is in charge of coordinating the data acquisition process from all ECNs, deploying algorithms, and balancing computing, networking, and storage resources. The orchestration of modular services using model-driven logic provides quick development and agile deployment through the edge gateway. ECNs are also in charge of network tapping, which keeps track of all packet transfers over networks between clients, terminals, Internet of Things devices, and cloud servers. ECNs can offer extra functionality by monitoring packets and altering them.

Distributed ECNs are present in the base layer. A protocol converting network switch, real-time closed-loop programmable controller, local cloud for big data analysis, and inexpensive sensor might all be performed by an ECN. Based on real-time closed-loop feedback data, these attributes might be dynamically assigned to any combination of industrial edge nodes.

3. METHODOLOGY

Industrial edge computing offers interoperability, real-time data processing, and self-optimization as a supplement to industrial clouds, which are not their primary focus. Interoperability ensures vertical and horizontal integration from device-to-device data interchange through system-to-system data migration. The complete manufacturing cycle, including product design, production, management, supply chain, etc., can be incorporated with flexible and distributed cooperation in ECNs. Next, by incorporating cloud-edge cooperation into new business models, resource consumption can be maximised. The workload of industrial clouds will decrease as a result of real-time data processing at the edge.Data acquisition pre-processing, calibration, and conversion can be completed in real time on edge devices without sending massive data to industrial clouds. Finally, by a mixture of industrial cloud and edge computing resources, data-driven optimization could be extended to edge nodes. Real-time constraints, as well as data efficiency, could be met by adopting pre-trained machine learning models from industrial clouds and distributed reasoning. ECNs must have certain fundamental compute, storage, and communication capabilities in order to satisfy these goals. First

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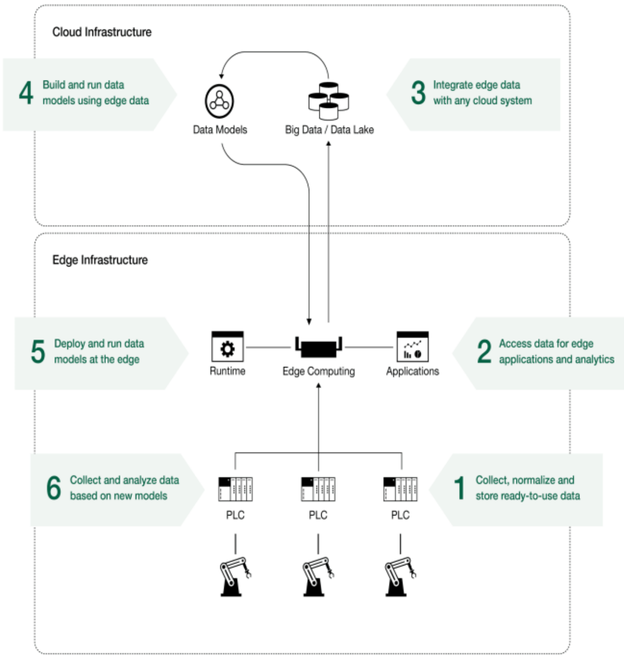
and foremost, the capacity to implement autonomous control is a crucial requirement for industrial edge computing. With the support of ECNs, the accuracy of automatic control for machines, systems, and processes could be enhanced with automatic fault detection, information processing, and operation control techniques while real-time constraints are assured. Secondly, instead of processing data using data center or cloud, data mining and analysis could be handled at the milliseconds level purely relying on the edge computing resources.



The effectiveness of data analysis will be significantly increased by reducing the time between communication between the edge and the cloud. The third criterion is optimization, which heavily depends on knowledge discovery and data mining. Data filtering and buffering should be a feature of industrial edge computing to cut down on computation and communication costs associated with erroneous information, increase data correctness for data recovery, and analyse the entire production process. But some resources are necessary to fulfil these demands. The communication resource is one of these resources. Industrial ECNs must offer flexible deployment in addition to ensuring data accuracy and deterministic transmission latency. The main technologies for supporting industrial edge computing include the TSN [9] [10], SDN [11], and real-time Ethernet-based solutions [12] [13]. The computer resource, particularly heterogeneous computing, is the second resource.. With increasing complexities of computing (machine learning models) and data structures (relational and non-relational) from the edge side, heterogeneous computing models combining sensors, controllers, gateway, and even local clouds are essential for balancing performance, minimizing operation cost, energy consumption, and improving portability. The third resource is the storage ability for edge devices. To trace information with millisecond intervals from sensors connected to the physical world, massive data must be collected, filtered, and buffered prior to further analysis either on the cloud or just using edge. Time series databases become popular for industrial edge computing for rapid insertion and query without updating legacy data records. The last resource is virtualization technologyThe development and deployment costs could be significantly decreased by swiftly transferring applications between various hardware and software environments by incorporating virtualization into embedded resources. Some fundamental characteristics and capabilities of an edge computing resource are essential for machine intelligence, self-management, and interoperability. To ensure dependability, real-time performance, and precision of control level in the automatic control domain, sensing and actuating, information modelling, and asset management are essential tasks. ECNs should use machine learning-based data mining, stream data analysis, and image and video

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processing for data analysis. Massive data generated from sensors could be pre-processed and invalid data could be filtered to reduce transmission bandwidth required between cloud and edge. On the other hand, time-sensitive data analysis tasks could be switched to the edge to reduce delay caused by data transferring. For optimization, industrial edge computing covers almost every domain, for examples, reducing bandwidth, device preventive maintenance, parameters optimization for real-time control, fault detection, planning prediction, and supply chain optimization. Overall, the industrial edge computing provides new challenges for legacy industrial automation systems as well as information and communication systems.

4. APPLICATIONS

Industrial Edge computing applications are expected to cut across every industry in which real-time data processing is required. Some of there applications are:

Autonomous vehicles: Edge technologies can help By sending information on accidents, traffic, weather, and other topics, edge technology can assist autonomous vehicles in communicating often.

Security: Installed edge computing devices operate as a security surveillance system by identifying and flagging anomalous behaviour in real-time, which finally results in counteractions as soon as possible.

Cloud gaming: The newest form of gaming, known as cloud gaming, broadcasts live video to devices. To reduce latency and provide a responsive and immersive gaming experience, cloud gaming businesses use edge computing technology to construct edge servers near players.

Manufacturing: Industrial gear may now make decisions on its own thanks to edge computing. Time and money are reduced because to the decentralised architecture. Robotics-driven production is likely as edge computing develops the architecture for machine learning networks.

Financial Sector: Banks can create general and white-label branches with remote assistance from edge analytics and machine vision. As a result, clients can access financial banking services and products worldwide.

Healthcare: Edge computing attempts to improve connectivity between machine-to-machine and machine-to-human interaction in the healthcare industry. This processing procedure can also assist in bringing medical software and services to isolated rural areas by distributing workloads at branch data centre locations.

Traffic Management: One of the best ways to improve real-time data is to optimise traffic management systems. Particularly for traffic control procedures, intelligent transportation networks heavily rely on edge computing technology

Oil and gas industry: In the oil and gas sectors, real-time remote monitoring is crucial. At remote locations, cutting-edge equipment driven by IoT sensors is set up to protect vital systems and machinery from calamity.

Smart cities:Without edge computing technology, smart cities would not exist. The heart of the development of smart cities is information collection by edge computing devices for basic processing activities.

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5. CHALLENGES

- 5G-Based Edge Communication: High transmission rate and minimal delay are the primary criteria and aims of IIoT edge computing, which frequently schedules and exchanges data between edge devices and edge servers at each tier. In terms of the transmission rate and low delay necessary to reduce certain economic losses and life-threatening emergencies, such as the emergency stopping of industrial equipment or autopilot vehicles, the three characteristics of 5G technology—an ultra-high rate, super-large connection, and ultra-low delay—can precisely meet the requirements of an IIoT system based on edge computing. Additionally, 5G can free up a lot of devices from cables, increasing physical deployment flexibility and requiring less upkeep. Despite the bright industrial future, 5G's incorporation into.

- System QoS
- Edge Node Management
- Network Slicing
- Data Offloading and Load Balancing: In IIoT systems based on edge computing, data offloading and load balancing are always major issues since there are too many devices and too many dispersed computing resources that need to be scheduled. Data offloading and load balancing strategies should be created for specific requirements in order to address these issues.. As for data offloading, the schemes currently applicable to conventional edge networks can be divided into two categories: full data offloading and partial data offloading. Full data offloading schemes offload all data from a device or edge server to others; while the partial data offloading schemes first divide the task data, and then offload a part data to different devices. The worst case is to offload all the data to other devices. The fundamental goal of the load balancing technique is to even out the uneven load distribution brought on by the various storage and computation capabilities of the edge device and the offloading strategies. In short, an important research direction is load balancing based on individual traits and scenarios incorporating new technology.

6. ADVANTAGES

- Lower latency
- Reduce bandwidth utilization
- Improved security
- Real-time of data analysis
- Scalability

7. CONCLUSION

When compared to the existing system, the proposed system is significantly more effective in terms of security, data analysis, and lower bandwidth usage. The industrial edge computing aids in reducing latency and scaling up data processing. By utilising edge computing technology in the IIoT, a portion of massive amounts of real-time sensor data can be processed close to the data source on the edge of the network, overcoming a major issue with slow decision-making from cloud platforms and restricted transmission capacity. In this study, industrial edge computing is thoroughly reviewed, the development and integration processes are explained, and a reference architecture for edge computing is proposed. We have provided a thorough explanation of the difficulties associated with edge computing, analysing and discussing them from the perspectives of load balancing and 5G-based edge communication. This paper's main contribution is to highlight the fusion application of industrial edge computing, attempting to elucidate the significance of industrial edge computing's future.

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