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IoT Data Management and Analytics: Challenges, Solutions & Trends

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Abstract

The Internet of Things (IoT) has revolutionized industries all over the world by introducing an era of unprecedented data generation and connection. Organizations must successfully manage, analyze, and derive meaningful insights from the massive amount of data that billions of devices routinely collect and transmit. This study examines the crucial facets of IoT data management and analytics, as well as the methodology, resources, and best practices that let businesses make the most of their IoT data. The fundamental properties of IoT data, such as their volume, velocity, diversity, and truthfulness, which provide particular obstacles in terms of storage, processing, and analysis, are first described in the study. The importance of data governance and security in the context of the Internet of Things is then discussed, with a focus on the necessity of effective data management techniques to guarantee data integrity, privacy, and compliance with legal requirements. The study incorporates case studies and real-world examples to show how IoT data management and analytics systems may be used in a variety of industries, including manufacturing, healthcare, smart cities, and agriculture. This study 's conclusion emphasizes the critical role that efficient IoT data management and analytics play in maximizing the potential of the Internet of Things. It is a helpful resource for businesses looking to use their IoT data for improved decision-making, efficiency, and competitiveness in the digital age by offering insights into best practices, cutting-edge technologies, and practical applications.

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1. Introduction

In its early days, only a small number of private businesses and government organizations had access to the internet. Tim Berners-Lee's invention of the World Wide Web (WWW) in 1989, however, drastically altered the environment and enabled broad internet access. Businesses all around the world then started creating their websites and connecting with clients online.

The introduction of the mobile revolution in the early 2000s marked the next key turning point in the development of connected technology. The first smart phones were introduced during this time by renowned electronics makers. There will be roughly 5.1 billion distinct mobile subscribers by 2019 and beyond, and there will be close to 9 billion linked gadgets. The next significant development in the development of networked information technology is the Internet of Things (IoT). Through the Internet of Things (IoT), connectivity is expanded beyond mainframe computers and mobile devices to include a wide range of physical items in several commercial, industrial, and consumer applications. As a result, an IoT device is any gadget that can connect to the internet, and there are billions of them in use today.

IoT platforms play a pivotal role in today’s technology architecture. The main benefits of IoT platforms is stated below:-

- It is much quicker and cheaper to bring connected products to the market and monitor operations.
- It makes simpler for developers to code and deploy applications for IoT solutions.
- It provides an efficient edge to cloud communications.

i. The six various groups of platform services are hereby mentioned: -

- The first among them is more often infrastructure cloud backend.
- The second is industrial data connectivity.
- The third is telecoms which is more around building the connection.
- The fourth is the device management which is about over the air updates and controlling firmware.

- Fifth is application enablement which is about ascertaining the fact people can actually make something.
- All the above-mentioned groups lead into advanced analytics having the subcomponents of tailored analytics and AI/Machine Learning.

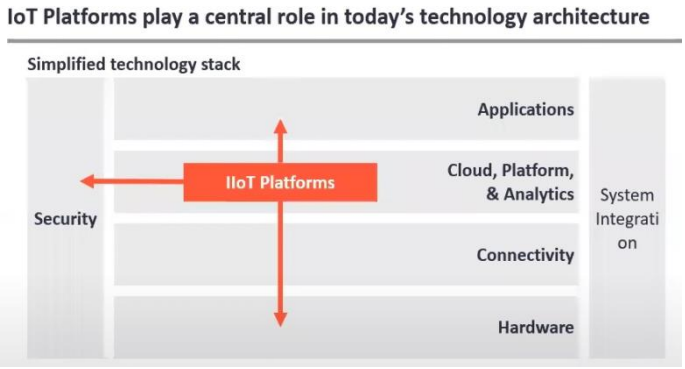

Figure 1. Representation of IOT in Technology Architecture [13]

2. Data Management and its Benefits

The main benefits of good data management and analytics are cost reduction. The other benefits include improved health of portfolio- knowledge transfer, informed culture- product development, scalability- extended asset lifespan, cost reductions- compliance, operational efficiency- safety and better resource allocation. [2,3]

2.1 Implementation of Data Management and Analytics from the User End

The typical flow of activities in context to this are divided into three categories

- Data Management[2,3]
- Analytics [2,3]

2.1.1 Data Management

Data management is currently thought of as a decision maker having to determine the data security requirements, how to process data, what data requirements there are, and what level of visualisation is required.[1]

Good data management starts from security. Data processing is done through different steps like data coding, data normalization and data cleansing. So far data requirements are concerned; data needs to be useful in relevancy, sufficiency and quantity. The different ways

to visualize data are time series visualization, metrics visualization and advanced visualization.[1]

Moving to the next flow of activities is Analytics. Here the type of analytics needed is reviewed. It depends on the goal of analytics whether it is descriptive, diagnostic, predictive or prescriptive.

2.1.2 Analytics

(i) Descriptive Analytics

It describes the measures taken. The steps followed here are

- Retrospective analytics of enterprise processes. [14,5]
- Business Intelligence. [14,5]
- Compile and evaluate. [14,5]
- Performance figure definite. [14,5]
- Data Aggregation. [14,5]
- Data mining. [14,5]
- Production Analytics examines which machine has the most downtime. [14,5]

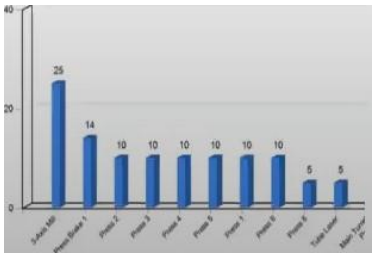

Figure 2. Descriptive Analytics [13]

(ii) Diagnostic Analytics

It examines reason for failures in the machine, the cause and as well as the effects of the failures. The necessary steps taken are as follows

- Identifying Anomalies. [6,17]
- Determining Casual Relationships. [6,17]
- Detect Patterns. [6,17]
- Reading time series data. [6,17]
- Drill down capabilities. [6,17]

- A/B Testing and multivariate testing. [6,17]

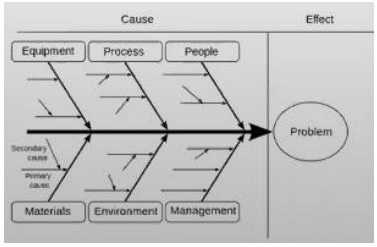

Figure 3. Diagnostic Analytics i[13]

(iii) Predictive Analytics

The analytics that enables in predicting/forecasting the future is called as the predictive analytics. It helps in forecasting whether the machine is about to fail? The steps followed here are

- Forecast activity, behaviour and trends.[9,18]
- Data collection. [9,18]
- Data modelling. [9,18]
- Pattern recognition.[9,18]
- Statistics.[9,18]
- Curve-fitting tools.[9,18]
- Machine Learning.[9,18]
- Text Analytics.[9,18]
- Estimating likelihood of failure- How likely is it for a machine to fail in the next weeks is shown in figure.4 below.[9,18]

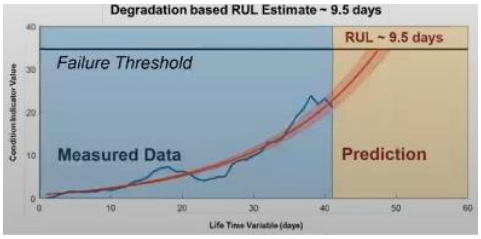

Figure 4. Predictive Analytics [13]

(iv) Prescriptive Analytics

It prescribes optional course of action in real-time. It analyses potential decisions, interactions between decisions. It also explores simulation and optimization techniques.

Besides, it goes for linear and non-linear programming.[10,11] The prescriptive analytics of the top driver is shown in figure.5 below

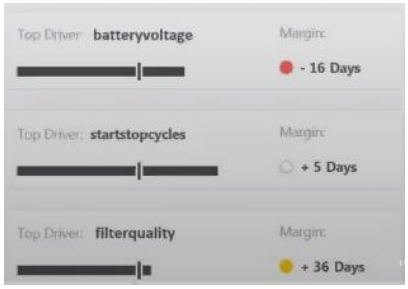

Figure 5. Prescriptive Analytics [13]

The top IoT use cases implemented by IoT platform users.

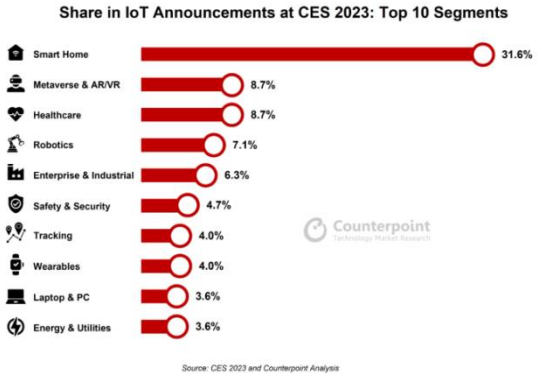

Figure 6. Representation of Top Segments of IOT User.[12]

2.2 IoT Visualization Examples

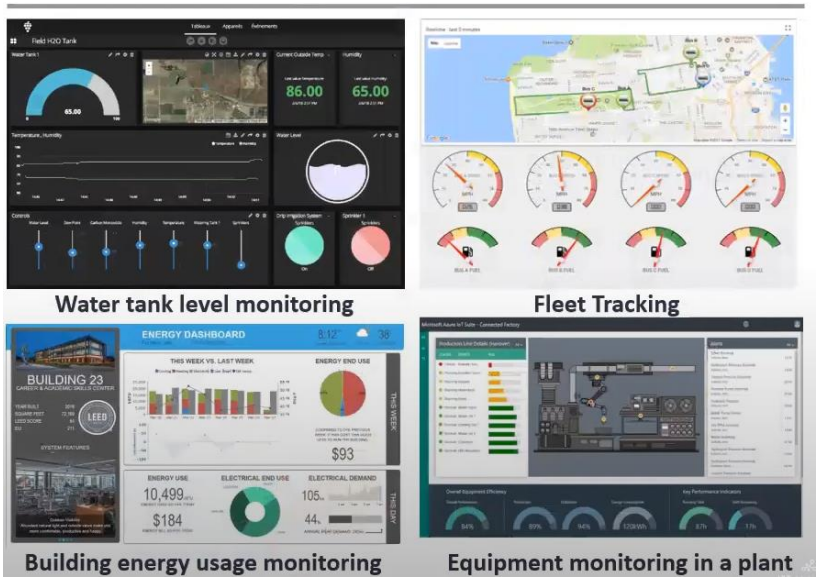

Figure 7. Representation of IOT Visualization Example [13]

The IoT visualization for monitoring the level of water, energy usage in a building, equipment in plant and fleet tracking are shown in figure.7. The methods of analytics to be used are different mathematical and algorithmic techniques leading to the same goal. The categories involved here are General Data Analytics, Supervised ML and Unsupervised ML. For predictive analytics, one has to identify which modelling strategy should be deployed, find out the desired model outcome and technique and trace the remaining useful life, probability of failure within a time window, flagging anomalous behaviour and survival model.

2.3 Data Requirements

Focusing on data requirements which is the most important aspect of data management, it is understood that a good model data needs to be relevant, in abundance and of high quality. So far relevance is concerned, for the kind of data required, domain expertise is leveraged to identify the right sources of data for a particular model.[4] Sufficiency stands as an important criterion then. It is significant to ensure that the right type of data is provided in the right level of abundance.[4]

To have right quality data, it is necessary that the noise and the data imbalances should be reduced to the minimum. To achieve this, different types of statistical techniques like sampling are used.[4]

3. IoT Data Management and IoT Insights

Bosch has evolved into a connected environment from its former focus on hardware technologies. The Internet of Things (IoT) has evolved into Bosch's main business strategy. The Bosch IoT Suite serves as the technical underpinning for Bosch's IoT solutions.[29]

The business leverages its IoT expertise through the Bosch IoT Suite to link a wide variety of devices across numerous industries, including building technology, consumer products, industry, and mobility solutions. This package functions as an all-encompassing IoT software platform, serving both internal and external clients. It consists of a number of cloud services and software programs that are all intended to help IoT developers create, deploy, and maintain IoT applications quickly, easily, and securely. The Bosch IoT Suite essentially serves as a comprehensive toolset designed in especially for IoT developers.[29], The Representation of Bosch IOU Suite is given in the figure .8 below.

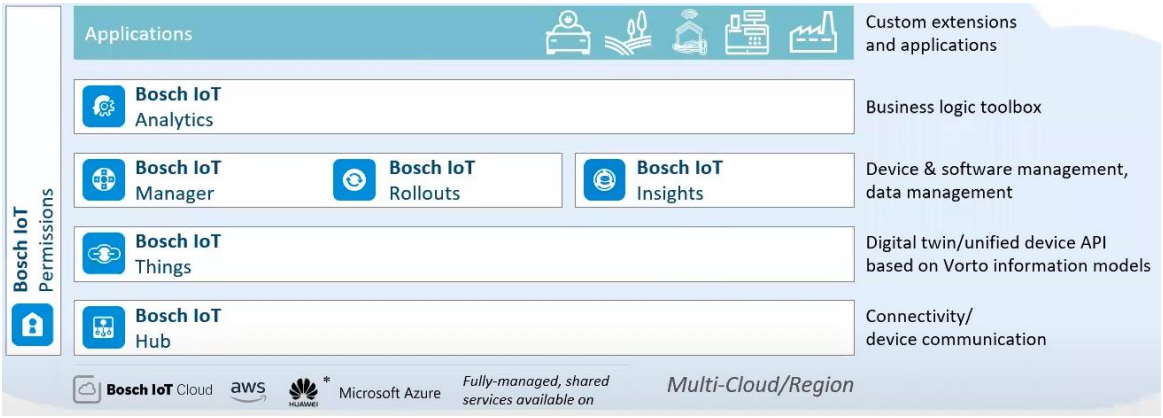

Figure 8. Representation of Bosch IOU Suite[13]

3.1 Bosh IoT Insights

To have a look at Bosh IoT insights, it started initially in 2013 with the first SFDE projects in the automotive sector in connecting over 100,000 devices. So, growing with more and more projects, SFDE as a cloud service was established and from that moment their customers were able to access their device from almost all over the world. In the year 2017, it was established as a cloud service. In the same year, the company celebrated its first non-automotive customer. This was a big step towards the market. In October 2018, it was established as a cloud service for IOT data management as part of the Bosch IOT suite.[29]

Bosh IOT suite family has various projects that are realized in over 10 countries across the world. Some of them namely are Russia, Japan, North America, Germany, China and so on. This demand is increasing. Innumerable companies face difficulty of not having their data managed appropriately. And here Bosch gathers feedback from the doers, the ones who know how the data management works.[29]

3.2 Key Challenges to IoT Data Management

- Technology Challenges

  i- Many existing protocols on the market that has to be implemented and configured. [7,8]

  ii- Real time requirements with related needs for speed processing and data analysis. [7,8]

- Data Privacy/Data Ownership Challenges

  i- Strategy and key security technologies required for data storage in relation to

GDPR. [7,8]

ii- Customers want to have control over the data and do the analysis themselves. [7,8]

- General IOT challenges can be stated as follows

  i- Mapping business value. [7,8]

  ii- High versatility. [7,8]

  iii- Solving connectivity issue. [7,8]

  iv- Existing sensors are not connected. [7,8]

  v- Willingness to use the cloud. [7,8]

- Data Quality Challenges

  i- Share information about a single data point with the other people. [7,8]

  ii- Too little data to perform big data operations. [7,8]

  iii- Understand all signals and connect them with the real world. [7,8]

The current figures of Bosh IoT suite achievements are mentioned as follows

- Data from nearly 4 million devices. [7,8]
- Managed data is about 2.5 TB. [7,8]
- More than 30 customer projects realized in over 10 countries worldwide. [7,8]

In order to guarantee total security for all elements of the IoT ecosystem, including endpoints, gateways, platforms, applications, and the data traffic that passes between these layers, AWS offers a comprehensive range of IoT services. Along with a streamlined, quicker, and more affordable way to attaining reliable, continuous, and scalable IoT security, compliance, and governance solutions, AWS also provides customers with a multi-layered security approach.[25]

4. Motivation

The Internet of Things (IoT) allows common physical things to communicate with one another by connecting them to the internet using a variety of data-sensing devices. Since it is gathered from a variety of sensors within the IoT ecosystem, data is essential to IoT. For production process optimization, error prevention, and cost reduction, an efficient data management plan must be put in place. Regardless of its origin or location, a strong data management system assures the timely supply of the appropriate data and includes components like data migration, security, and integrity. [13]

5. Literature Survey

- The idea of "Large Data Management in IoT Applications" emphasizes the difficulty of processing, visualizing, and extracting useful client data from sizable datasets kept on servers within IoT applications. Client requests to the database may incur substantial delays, especially in urgent situations. A separate data processing layer is utilized to "cache" fields depending on chosen or frequently used database queries in order to solve this problem.[29]

- The study explores the lifecycle of data inside IoT and looks at current research trends in the area of IoT data management, which has a sustainability focus. Since communication overhead and storage techniques have the biggest effects on energy usage, research on these topics is given the most priority.[20]

- A thorough analysis of suggested data management solutions for IoT or its subsystems is provided in "Data Management for IoT: Design Principles and Solutions". The study highlights important design concepts and presents a data management architecture specifically made for IoT, taking into account the design features covered. This framework acts as the conceptual basis for an all-encompassing IoT data management system.[21]

- The focus of this study is "Facilitating Queries for Frequently Updated Data from Mobile Sensing Sources," and it addresses two key problems:

i-Designing a standardized sensing layer that can accommodate the wide variety of mobile data sources is the first problem. [22]

ii-The second difficulty is in searching these sources' frequently updated time-stamped and structured (FUTS) data. [21]

- The "Efficient Storage of Multi-Sensor Object Tracking Data" study presents a novel method for streamlining the reading and writing operations for multi-sensor object tracking data storage on Hadoop Distributed File System (HDFS). In terms of disk write speed, memory write speed, search performance, and sensor clustering, the findings show that this idea is effective. [28]

- The study emphasizes the shortcomings of conventional data storage and query approaches in efficiently managing significant volumes of sensor data in the context of

"A Unified Storage and Query Optimization Framework for Sensor Data." The Cloud-Real Base, a framework for unified storage and query optimization, is proposed as a response to these restrictions and as a means of managing massive amounts of sensor data. [20]

- The emphasis of the study "Methods and Optimization Algorithms for Managing IoT Data in Mobile Publish/Subscribe Services within a Cloud Environment" is on defining design concepts for IoT data management strategies. In order to create a unified IoT ecosystem, this entails optimizing algorithms that use publish/subscribe middleware and connected data dispersed across mobile networks. [22]

- In "When Things Matter: A Data-Centric Perspective of the IoT," the emphasis is mostly on emphasizing important IoT strategies from a data-centric perspective. These cover topics including data stream processing, data storage structures, complicated event processing, and search techniques, all of which are crucial in determining the IoT environment. [213]

6. Present IoT Trends

IoT analytics estimated in May 2023 that there were 14.3 billion active endpoints worldwide in 2022, representing an 18% increase in IoT connectivity. According to IoT analytics forecasts, there will be 16.7 billion active endpoints worldwide in 2023, representing a further 16% surge in the number of connected IoT devices. [23]

Figure 9. Representation of Present IOT Trends.[26]

Significant advancements were made in the field of AI software algorithms and the hardware infrastructure that is needed to train these models in the year 2022. Many businesses are actively trying to speed up the rate at which data created by the IoT can be evaluated and turned into useful insights, both inside data centres and at the network edge. Additionally, as more IoT devices continue to collect data, there is a significant rise in the amount of data that is available for analysis and model training. Once these models have been created in data centres, it may be integrated into IoT endpoint devices or used as inference engines at the network edge, opening up the possibility of new and more effective applications. [5]

The use of IoT technologies in industrial settings increased in 2022, and a recent IEEE poll named industrial IoT as one of the most important technology domains for 2023. Concerns about infections during the pandemic and the need to manage labour shortages contributed to this increase. Robotics, automation, and local intelligence are being used by IoT-enabled factories to take over jobs that would often need close human presence. The intelligence built into IoT-based systems, along with the human efforts offers a safer and more effective manufacturing process. [16]

The progressive easing of chip shortages in 2023, by lowering the demand and new production facilities coming online, will be another factor facilitating the expansion of the IoT. Despite predictions that there will still be a chip shortage in 2024, price reductions for a number of chips, notably dynamic RAM and NAND flash, have been made as a result of a decline in demand. Reduced costs for IoT goods are anticipated to result from lower component prices, which might hasten their adoption and potentially lessen any economic downturn. [5]Traditional data centre servers are being broken down, and virtual computing systems are being built, resulting in more effective data processing and lower power usage. IoT applications account for a sizeable amount of the data handled in data centres, and as IoT adoption grows, so will the demand for data processing. [23]Emerging non-volatile or persistent memory technologies are starting to become noticeable in IoT devices in addition to traditional memory technologies. Some consumer IoT devices, such wearable, use magnetic RAM and resistive RAM in particular. Replacing static RAM with a non-volatile memory like MRAM has the benefit of consuming less power. This increases the usability and lifespan of the IoT device, which is especially beneficial for energy-constrained applications like those powered by batteries. [5]

The other main trends are:-

- Everything is becoming predictive. [16]
- Revival of basic statistics and visualization. [16]
- Data gets increasingly managed in the cloud. [16]
- Increasing use of AI/ML(also for data management) [16]
- Digital twins starting to play a more important role. [16]

7. Future Scope of IOT

One of the most promising technological advancements of the twenty-first century is the Internet of Things (IoT), which has the potential to fundamentally sustain and enhance the lives of people. With considerable investments being made to create a strong environment for its healthy development, the future of IoT seems tremendously promising.

India is about to see the internet-connected 500 million IoT devices, opening up new opportunities for innovation and professional progression. The opportunities offered by IoT are essentially endless, ranging from smart phones to connected cars and intelligent infrastructure.

The reasons why IoT should reign supreme are as follows:-

- The future is IoT
- IoT is anticipated to grow into a $1.6 trillion business with more than 75 billion connected devices worldwide in the near future.[27]
  All industries are embracing it more and more as businesses aggressively invest in IoT solutions to boost productivity, reduce expenses, and improve customer service.[19]
- High salary potential
  With an average yearly compensation of $110,000, professionals in the IoT domain are among the best earners in the technology sector.[19]
- Diverse career opportunities
  The IoT sector provides a broad range of employment options, from IoT developers and architects to IoT security experts and data scientists. IoT is a field that attracts people with a variety of educational backgrounds and skill sets because of its diversity.[19]
- Innovation and Creativity
  IoT is a field that places a high importance on creativity and innovation because experts working in it are constantly coming up with innovative methods and apps to handle complex problems.[27]
- Impact on Society
  The Internet of Things (IoT) has the potential to transform numerous industries,

making them more effective, sustainable, and safe. Being an IoT expert entails helping to develop solutions that could significantly affect society.[27]

- In-Demand Job Roles in IoT
  i- IoT Developer
  ii- IoT Architect
  iii- IoT Security Specialists
  iv- IoT Data Scientists
  v- IoT Product Manager
  In addition, there are lots of entry-level jobs in IoT that provide fantastic chances for career advancement. These include IoT project managers, IoT sales representatives, IoT application developers, IoT data analysts, and IoT technicians.[19]

7.1 Skills Required for IOT Professionals

A successful career launch requires the development of IoT skills, which include: -

- Programming Skills: Proficiency in programming languages such as C++, Java, Python, and Ruby.[15]
- Understanding of IoT Protocols: knowledge of IoT communication standards like MQTT, CoAP, and AMQP.[15]
- Data Analysis Skills: Competence in data mining and predictive analytics.[15]
- Cyber Security: Knowledge of network security, encryption, and secure communication protocols (SCP).[15]
- Cloud Computing: Experience with cloud platforms like AWS, Azure, and Google Cloud Platform.[15]

8. Conclusion

Every component of the IoT ecosystem produces data packets as a result of the rapid spread of connected devices, necessitating dependable connectivity, safe storage, and protection. IoT puts enterprises in the difficult position of having to efficiently manage, monitor, and gather massive amounts of data and connections coming from dispersed devices. However, these difficulties are not obstacles while working in a cloud-based environment. Additionally, cloud computing enables the worldwide and cross-regional expansion of IoT solutions, lowering communication latency and boosting field device responsiveness.

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