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Exploring the IoT Data Analytics Landscape: An Extensive Study

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Abstract: Since the past decade, the data production and consumption has been increasing exponentially. Ever since the emergence of cheap computer chips, wireless networks, and technological advancements in the cloud, there has been a tremendous increase in the number of IoT devices being developed. The data collected by connected heterogeneous IoT devices are highly diverse and unstructured and need to be analyzed to gain valuable insights therefrom. Data analysis can effectively help Internet of Things (IoT) businesses to identify trends, enhance growth and productivity, and empower employees. To date, immense opportunities are being discovered by analyzing massive amounts of data generated by IoT devices. Through an in-depth analysis of existing surveys, we explore IoT, data analytics, and their unification. In this survey, we investigated various applications with their extensive usage and significant challenges of IoT data analytics. By examining the plethora of advantages of data analysis in the IoT sector, one can conclude that field has numerous applications and the true potential of data analysis in IoT sector is yet to be realized.
Index Terms: IoT, data, processing, sensor devices, valuable insights, monitor, heterogeneous data.

I. INTRODUCTION

The IoT is one of the most propitious technological advancements in the current era, provided we are able to consume and discover its absolute potential. Since the past decade, the size of IoT devices has been decreasing [1] while the number of IoT devices in various sectors has been increasing exponentially, contributing to massive amounts of data [2]. Statistics reveal that 2 quintillion bytes of data are generated from IoT devices daily. Data produced by IoT devices is burgeoning at an ever-expanding rate and this unstructured data needs to be processed and analyzed to draw valuable conclusions therefrom. Technical developments, ease of use of IoT devices and the reduced costs of sensors and chips for capturing data are propelling the increased usage of IoT devices in different industry verticals. The present era of massive data collection, where traditional data storage and analysis techniques are not adequate, necessitates data analysis [3]. The huge volumes of data being produced by IoT devices need to be filtered and analyzed to obtain crucial insights from the system and its behavior [4]. Combining IoT and data analytics is creating value for businesses and organizations. The objective is to analyze and discover data trends and results to facilitate a positive impact on organizations. In a dynamic technical world, IoT data analytics is revolutionizing the way companies conduct business, whatever their size or activity. Irrespective of the field of business analysis of data collected from IoT devices, IoT enthusiasts and businesses need to convert data collected from their devices into valuable knowledge and achieve better outcomes from their connected devices. Immense opportunities are presented to business associations and organizations by data analysis concerning improving decision-making, optimizing operations, engaging more customers, empowering employees, etc. IoT data analytics can be used to improve customer experience by collecting data on their preferences, needs, price range, product reviews, etc. to improve organization's services and products accordingly.

Integrating IoT and data analytics has proved useful in remote healthcare monitoring, retail, smart cities, agriculture, business, manufacturing, intelligent shopping, smart gadgets, grid systems, smart transport, etc. [1].

This paper is organized as follows. Sec. II provides the background and motivation for studying IoT and data analytics and integrating the two fields. Sec. III discusses various applications of data analytics in different IoT domains. Sec. IV explores the various challenges faced in IoT analytics, while Sec. V provides the concluding remarks.

II. BACKGROUND AND MOTIVATION

A. IoT Domains and Applications

1) Internet of Things in Smart Cities

a) Effective Water Supply
b) City Lighting
c) Road Traffic

d) Citizen Safety
e) Smart Parking
f) Crowd sensing
g) Air Standard
h) Garbage Management
i) Environment

2) Internet of Things in Energy
a) Smart Meters
b) Mending and Maintenance

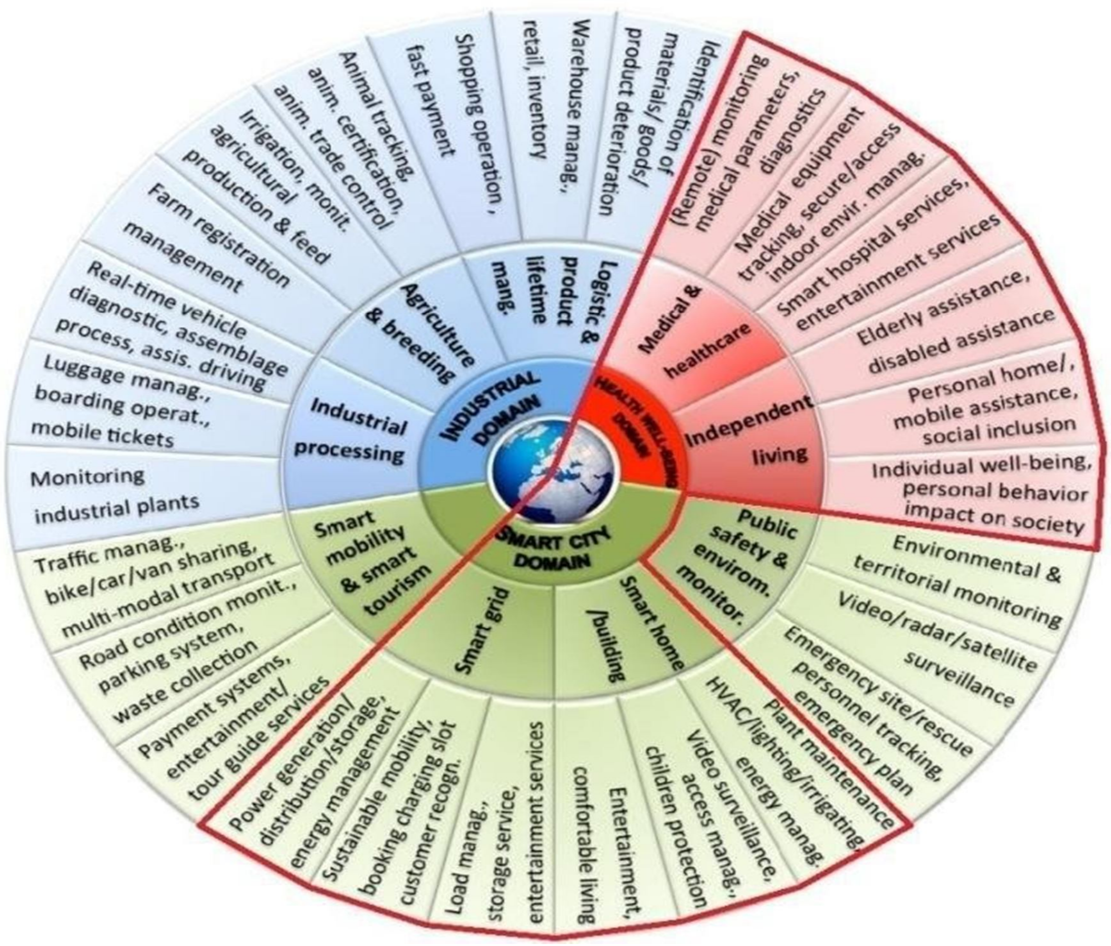

Fig. 1. IoT Domains [5]

c) Easy Collection of Consumption Data
d) Monitoring Water Services Remotely
e) Electricity Pole Surveillance

3) Internet of Things in Healthcare
a) Preferable Management of Drugs and Medicine
b) Same Time Monitoring and Reporting
c) Remote Medical Assistance
d) Minimizing Errors and Waste
e) Improved Treatment Outcomes

4) Internet of Things in Agriculture

a) Livestock Monitoring
b) Crop Management
c) Agricultural Drones
d) Greenhouse Automation
e) Autonomous Tractors

5) Internet of Things in Biometrics

6) Internet of Things in Businesses [6]

As IoT develops further, many more potential applications and domains will emerge, providing a vast array of services and advancements in different sectors.

B. Data Analysis Process and Life Cycle

1) Gathering data

Data collection is the process of gathering information to analyze the outcomes and use them for research and experiments. Collecting the right data is crucial while conducting research or experiments. Data can be collected through different techniques from various sources - interviews, websites, surveys, APIs, devices, etc.

While gathering data. following criteria should be satisfied:

a) Accuracy: Inaccurate data will lead to incorrect results.
b) Reliability: The data source data should be reliable.
c) Privacy: Only data to which the user is authorized should be gathered [7].

2) Accessing and Integrating Data

Data obtained from multiple independent heterogeneous devices are combined to finally form homogeneous data, which can be easily used for analysis and visualization. [8]. This step also includes exploring the data and looking out for quality and tidiness issues.

3) Data Cleaning

Data cleaning is the process of correcting irrelevant, incomplete, duplicate, and untidy data and irrelevant records and obtaining data of high quality [9]. Data are generated from multiple heterogeneous devices with varying quality levels, and cleaning is a cumbersome task. [10].

The quality of data depends on :

- Existence of data (in real world)
- Validity (whether the findings truly represent what the study is intended to measure)
- Integrity (accuracy of data over its lifecycle)
- Consistency (data is correct *vis-a-vis* other copies of data)
- Relevance (data applies to the problem at hand)

Poor quality data lead to poor decision-making, incorrect reporting, and unreliable analysis. This can cause a huge loss to all data-oriented sectors [11] [12]. Dirty data is the biggest hindrance to rich-quality data analysis and causes huge losses to businesses [12]. Data need to be cleaned as they affect assumptions as well as results.

Data are cleaned by :

a) Correcting inconsistent column names
b) Removing/filling in missing values
c) Removing duplicate rows
d) Correcting data types of columns
e) Removing irrelevant information
f) Handling outliers:

- Changing the value of outliers
- Removing outliers
- Considering the value of mild outliers
- For data input errors, using clustering algorithms to find the value closest to the given outlier [9]

4) Data Analysis and Visualization

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Analyzing data means obtaining valuable results from the cleaned data, using search queries, and bringing order and structure to them. Using massive amounts of data in an easily understandable format is enabled by visualizing data. Data analysis techniques like qualitative, quantitative, predictive, and statistical analysis and data visualization techniques like tables, charts, and maps facilitate understanding the data and deriving conclusions. Models like correlation, regression analysis, etc. enable identifying the relationships between different attributes, thereby simplifying analysis. Graphical representation of data helps in finding patterns and communicating results effectively.

5) Communication

Results obtained from the analysis and visualization need to be communicated in an accessible and understandable form which makes the decision-making process simpler for consumers and business ventures. Data analysis concerns not only producing graphs and interpreting conclusions but also effectively translating the results that are helpful to the organizations.

C. Proposed IoT architecture for Data Analysis

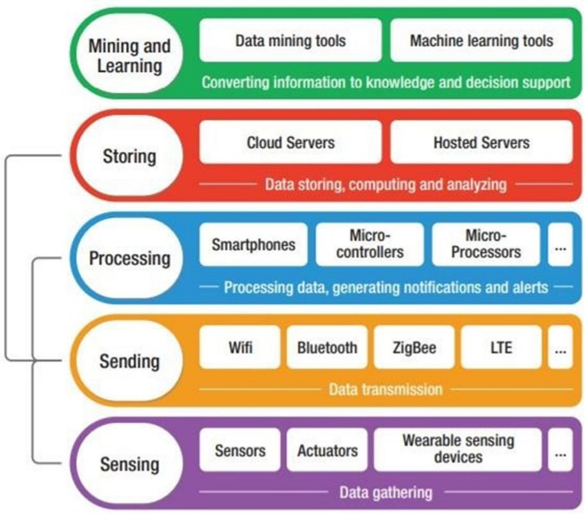

Fig. 2. IoT Tiered Architecture [13]

III. APPLICATION OF IOT AND DATA ANALYSIS

A. Healthcare Domain

Continuous health monitoring is useful in maintaining the health of individuals, which can increase the quality of life. IoT can be used to reduce not only the load on healthcare providers but also the expenditure of healthcare facilities. Some of the applications of IoT in the healthcare domain are as follows:

1) In Hospitals

In paper [14], the authors implemented a healthcare system for hospitals to monitor the temperature of patients at regular intervals. They used an Intel Galileo generation 2 board to process the received data, and an XBee Series 2 device supporting Zigbee mesh protocol which is further connected to a temperature sensor for attaining the required values. The Intel board was used to store, process, and analyze the data and send the final desired data to the cloud through a secure connection. This system helped in measuring temperature at regular intervals and can depict any major changes from the initial stage. It enhanced the cost and quality of care required for patients and simultaneously collects and analyzes data.

2) Chronic Diseases

Chronic diseases are increasing at an alarming rate. Sensors can be used for monitoring the levels of diabetes, blood pressure, heart rate, the weight of the person being monitored, etc. to trigger alarms in the event of any abnormal situation or for early treatment of the patients.

In paper [15], the authors discussed various applications of data analytics in different healthcare applications. Type 2 diabetes and hypertension can be predicted using a random forest algorithm. For cleaning the data obtained, density-based spatial clustering and synthetic minority over-sampling were used. By using these methods, significant accuracy, sensitivity, and F1 score were obtained, compared to the existing models. These authors also discussed the relationship between continuity of care for diabetes patients and the clinical results thereafter. In this, statistical analysis was used to determine the required relationship.

3) Elderly Assistance

In [13], the authors proposed a system- Silver Link- which uses human and object sensors to monitor the daily activities of aged people. This system can empower individuals, especially the aged, to maintain their health status. There are similar systems such as Help to You(H2U) which monitor the health status of people by using biosensors; extra facilities are also included, such as emergency calls and medication reminders. In this paper, an IoT architecture was proposed in five tiers for monitoring the patients as in sensing by recording health parameters, sending layer to connect and share data, and processing layer to process the data which consists of software applications and processing units, storing layer to generate huge data for efficient storage and mining, and learning layer support machine learning and data mining processes. These machine learning and mining technologies were used to obtain feedback from the model layers but not from the clinicians directly.

4) Wearable Devices

In paper [16], the authors discussed the basic technology of wearable devices. Intel Galileo Gen 2 was used for storing the health information of patients in the Cloud. The Cloud can efficiently handle the scalability of data. Patients' data is periodically analyzed in real-time with a small response time using Hadoop. The proposed system helps doctors to provide timely healthcare assistance to the required patient. The system developed is successful in providing customized care to patients.

5) Health Monitoring

The authors [17] examined the IoT monitoring devices for observing patients while at home, their status being checked by doctors. Ordinarily, text-based notes are taken for huge information investigations in medical services enterprises. In this paper, the author proposed health monitoring devices which include a Microsoft APS Appliance, along with a huge health system client which helps in generating an extremely parallel data structure for the health industry. Both of them comprise the Hortonworks Hadoop Cluster. From this, it is presumed that a major information bunch and conventional social data set could be run equally. The information-preparing power is expanded considerably by questioning both information stores simultaneously [17].

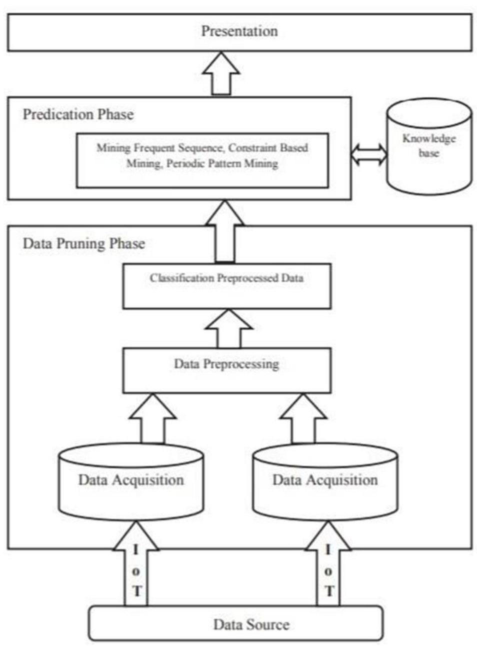

Fig. 3. Inferring Information and Knowledge from Healthcare Data [18]

6) Health Tracking Devices

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In this paper [17], the authors proposed Health Monitoring Sensors to sample the physiological signals of the patient. The IoT has the framework engineering for the huge information investigation in medical care. The circulatory strain sensor, pulse sensors, and stickiness sensors were combined with the health care intermediary. The IoT agent played the role of a health proxy. The identified healthcare boundaries were sent to the cloud. Cloud technology is preferred to handle a colossal proportion of clinical administration data emanating from patients across different clinical administration associations. Further, recorded examination of the healthcare data of a specific patient is conceivable in the cloud, with the put-away information. Since there is a facility to connect the mobile phone directly to the IoT agent through GPIO pins, the doctor's mobile phone could be used to gather the healthcare information of a specific patient.

7) Emergency Application

Concerning [19], emergency applications involving IoT recognize variations from the norm at the perfect time, to caution crisis administrations. A model to do this includes observing the patient's health through medical devices; from that point, personal mobile devices analyze the collected data to identify emergency cases and move information to medical data frameworks. When a particular emergency case is detected, the ambulatory team can reach out to the patient. Consequently, the hospital prepares for the clinical treatment, and the medical personnel send situation-aware instructions for providing first aid.

B. Smart City Domain

As stated by United Nations, currently, 55% of the world's population is living in urban areas, which is expected to increase to 68% by 2050, potentially resulting in an excessive burden on living conditions. More and more cities are beginning to use data analytics and IoT to avail the power of sensors, cloud computing, and high-speed networks, which can make smart cities sustainable and offer an enhanced quality of life [20] [21]. Data is being produced at such high rates from IoT devices that the need to understand how data is generated, transported, and evaluated will increase extensively in the upcoming decade. [22].In a smart city, sensors collect data regarding the environment, security, agriculture, traffic, waste, mobility of citizens, etc. and the insights obtained therefrom are used for optimizing operations, automating tasks, etc. effectively. Some applications of IoT analytics in smart cities are presented below:

1) Smart Traffic Light System

Traffic jams are a problem for almost every major city in the world, and can cause loss of money, time, and substantial and harmful carbon dioxide emissions. Developed countries are trying to reduce traffic issues through the use of IoT data analytics. Authors in [21] discussed the use of sensors across the city to detect different parameters of traffic flow like velocity, occupancy rate, traffic flow rate, density, waiting time, lights, traffic jams, etc.) and make predictions and decisions accordingly for traffic lights.

In reference [23], the authors proposed a smart traffic management system that could be implemented at a significantly lower cost than the existing models for updating traffic details instantly. In this system, traffic data can be collected from various vehicle-detecting sensors embedded in every 1/2-1 kilometer. By decreasing the distance between the sensors, the accuracy of the device increases. A minimum of 10 sensors are connected and managed by an Intel IoT kit which is further connected to the network. This model is successful in analyzing traffic density, which is communicated to the users through a mobile application.

IoT data analytics is also capable of analyzing alternative routes by itself, thereby reducing hectic traffic issues. It can also be used to predict busy traffic hours for different areas from past data and suggest suitable routes beforehand, making commuters' lives easier.

2) Smart Agriculture

Agriculture, in today's world, is data-c eprecise, and smarter than ever, despite people's current perception of agriculture. Using smart agriculture, farmers can keep track of crop field conditions from anywhere, automate irrigation systems, analyze suitable crops for specific climate conditions, etc. Using IoT analytics in agriculture, farmers can reduce waste and enhance productivity.

In [24], the authors proposed a smart polyhouse system to increase the quality and yield of crops, along with automating the functionalities of the polyhouse. In this system, the authors used sensors, IoT devices, and Hadoop technology to successfully control and monitor the soil moisture, temperature, and humidity required for optimum crop growth.

In [25], the authors developed a model to centralize monitoring and control for the agricultural land using which one can:

a) Collect environment, soil, and irrigation data

b) Wirelessly control field devices
c) Track dates of sowing of seeds, adding manure and fertilizers, harvesting, threshing, and storing.
d) Gain insights into weather forecasts and weather changes
e) Compute crop forecasts and predictions
f) Collect the latest news of agriculture and farming to keep the farmers updated about current trends

The authors developed a multi-utility mobile application with the aforesaid features.

3) Smart Crime Detection

Using IoT data analytics, criminologists can identify areas and times where crime is frequent. Significant success in using predictive analysis for predicting crime locations through historical and geographical data has been achieved in London, Los Angeles, and Chicago.

In [26], the authors developed a smart crime detection system for detecting crimes by analyzing human emotions instantly. Data are collected by wearable sensors that detect heartbeat and internal temperature and a CCTV programmed to recognize 36 emotions. After real-time analysis of emotion detection and recordings, the system further notifies police and guardians in case of any unusual activity. Crime data are stored in a database to visualize through web-based GIS for helping to predict future crimes.

In [27], the authors developed a model by combining neural networks and a hybrid deep learning algorithm for analyzing videos to detect violence and theft. By the object-tracking method of DCNN and RNN network, abnormal and unusual behavioral patterns are detected. The video analysis feature can detect thefts through deep learning algorithms by separating normal behavior from learned violent criminal behavior. This model can be applied to CCTV security cameras to alert security officials, thereby reducing their load and increasing public safety.

4) Smart Transportation

Smart transport was effectively used during the London 2012 Olympics to deal with 18 million journeys made throughout the games. Train operators used data analytics to predict the number of journeys to effectively transport spectators and athletes and make arrangements accordingly.

In [1], the authors pointed out the difficulties in traditional transport systems which are affected by weather conditions. They discussed the feasibility of an e-plate system using RFID technology that could provide a solution for intelligent monitoring, tracking, and identification of vehicles.

IoT data analytics could be used for

a) Real-time prediction of public transport by accurately predicting traffic congestion
b) Bike-sharing system for predicting the load at individual stations by evaluating the bicycle journeys in different regions.

C. Industrial Domain

The Industrial Internet of Things (IIoT) (also known as Industry 4.0), which was at first considered a dream by the German government, is right now credited as the fourth industrial revolution. The technology ecosystem supporting IoT is mainly the incorporation of cyber- physical systems (CPS), Internet of things (IoT), cloud computing, automation (e.g., savvy robots in item sequential construction systems), Internet of services, wireless technologies, augmented reality, and concentric computing, *inter alia*. Advances in such related regions asIoT, big data analytics (BDA), cloud computing, and CPS have fueled the development of IIoT exercises to convey extraordinary adaptability, precision, and efficiency to manufacturing measures. Given this inter-platform integration, Interoperability, virtualization, decentralization, real-time capability, service orientation, modularity, and security are some of the features that IIoT systems must ensure [28].

Generally, Industrial Automation and Control Systems (IACS) and conventional digital networks such as enterprise ICT environments were never used together and had their boundaries. Where availability was required, drafted engineering was embraced, with firewalls as well as neutral territories used to secure the center control framework parts. The inclusion and organization of IoT innovations initiate structural changes to IACS, including better connectivity to industrial systems [28].

The industrial sectors illustrated in Figure 4 are the most relevant ones with IoT as a concern. These sectors use the maximum number of IoT devices deployed in the organization's operational systems. All the sectors use IACS to different extents, and according to the trends reported by the industrial market, the use of IIoT is likely to go up [29].

Fig. 4. Industrial Sector Architecture [29]

1) Smart Factory System

In [30], the authors focused on vertical integration to implement adaptable and re-designable smart factories.

They first proposed a concise system wherein smart artifacts such as machines, products, and conveyors are consolidated with modern remote organizations, cloud, and fixed or versatile terminals. At that point, they explained the functioning component from the perspective of control design, viz., the self-organized system assisted by the feedback and coordination blocks of smart artifacts based on big data analytics and executed on the cloud. They held out the hope that the smart factory of Industry 4.0 is attainable by widely applying the current empowering advancements while effectively adapting to overcome specialized difficulties.

In reference [31], the authors proposed a model with two- priority queuing for scheduling and analyzing the IoT data. The data obtained from IoT devices, along with requests, are divided into two categories–high and low-priority requests. High-priority requests are urgent or emergency demands that should be planned quickly. Finally, the authors further introduced a workload assignment algorithm in which they reduced the peak loads over higher tiers of the fog hierarchy. Finally, they compared the benefits of the proposed architecture to the conventional flat design that has been proved using various performance metrics and through extensive simulations, using realistic industrial data from the Bosch group.

2) Intelligent Logistics System

In reference [32], the authors proposed an IoT-based intelligent logistics dispatching framework, which empowers dynamic coordination between clients, robots that pick orders, and cloud technologies and innovations. This framework incorporates three formats: the system structure of an intelligent dispatching platform based on an IoT environment; the multi-target advancement model to accomplish the productive powerful coordination between clients, robots that pick orders, and cloud technologies and innovations; the core two-level algorithm, which comprises Dijkstra's algorithm and ant colony algorithm that underpin the intelligent dispatching operations. They claim that their research is capable of efficiently coordinating dispatching operations through IoT technology to enhance customer satisfaction and outperform traditional dispatching methodologies.

3) Smart Manufacturing System

Technologies such as cloud computing, IoT, big data, and artificial intelligence are undergoing rapid development in recent years and are thus pervading the manufacturing industry. The inclusion of the above stated technologies has enabled this industry with the fusion of physical and virtual worlds through cyber-physical systems (CPS), which mark the origin of the fourth stage of Industry 4.0. The far-reaching use of CPS in manufacturing environments renders manufacturing systems progressively savvy.

Paper [33] examined smart manufacturing systems under Industry 4.0. First, the authors introduced an applied structure of smart manufacturing systems for Industry 4.0. Next, demonstrative scenarios that concern smart design, smart monitoring, smart machining, smart scheduling, and smart control, were shown. Key advancements and their potential applications to Industry 4.0 smart manufacturing systems were analyzed based on these demonstrative scenarios. Supply chain industries can become more efficient, productive, and smarter by embracing the empowering advances of Industry 4.0.

4) Supply Chain Management

Supply chain industries are working with restricted overall efficiency and productivity. They can become more efficient, productive, and smarter by adopting the enabling advances of Industry 4.0. In paper [34], the authors developed an IoT-based conceptual framework for the supply chain industry. The principal points of the proposed IoT-based structure were to increase the performance of the members of the supply chain through enhanced data sharing and well-organized asset utilization. The authors carried out a keyword-based literature review and developed the IoT-based conceptual framework for SCM based on the literature review. This paper proposed a structure that centers on the development and enhancement of a smart supply chain management system. The proposed IoT-based structure has a data assortment gadget, a coordinated data management framework, and a vast network.

IV. CHALLENGES

A. Security

1) The massive amount of data generated by IoT sensor devices needs to be protected from falling into the wrong hands. Authorization, amount of accessible data, and encryption key management need to be focused upon to prevent cybercriminals from gaining access to the data.
2) In some cases, the service providers use third-party tools to manage and analyze data generated from IoT devices, which elevates the risk of data exposure.
3) IoT data analytics, being a relatively modern field, lacks experienced security specialists.
4) The interconnectivity of IoT devices increases the threat of malware spread and the entire data being disclosed. Identifying the root cause of suspicious traffic patterns is worsened by the network architecture.
5) Data generated from confidential and private sectors need to be securely transmitted.

B. Data Volume

1) The high data production rate of IoT devices causes storage issues and terminates successive data analysis processes.
2) Data collected from IoT sensor devices is highly redundant [35].
3) Prevalent preprocessing methods are unable to handle IoT data.
4) Companies need to choose between storing raw data for better accuracy or optimizing the volume of incoming data (by discarding data) and risk valuable insights and results.
5) Traditional relational databases are incapable of handling huge amounts of heterogeneous data generated.

C. Time and Location

1) Due to poor network connectivity in remote areas, huge amounts of data are lost, affecting the overall analysis process.
2) The available charge of cells for solar-powered IoT devices affects the frequency of data reporting, causing loss of data.
3) IoT devices are spread around the globe and have different local times. Lack of details about the type of clock (UTC or local time) can drastically affect analytics results.

D. Data Visualization

1) Data visualization is a key concept in determining conclusions in IoT data analytics, due to the enormous amount of data generated from IoT devices. Generating visualizations in a small response time from diverse heterogeneous data is a challenging task.
2) Enormous amounts of generated data are distributed among various servers. Decomposing data into independent tasks and executing queries concurrently for parallel visualization is another challenging task.
3) Current tools available for data visualization present poor results due to rapid data changes, visual noise, high performance demand and applying reduction methods. [1]

V. CONCLUSION

IoT devices generate heterogeneous and diverse data whose full potential can be realized only on analyzing them; thereby, data analytics comes into play. Data enthusiasts can efficiently convert data collected from various devices into valuable knowledge. Further, data analytics can prove to be a successful tool for new IoT applications. In this paper, a survey of existing papers on the integration of IoT and data analytics was conducted. Herein, we studied the field of IoT and data analytics and their integration. We investigated numerous notable applications of IoT and data analytics in different domains. Further, the challenges of IoT and data analytics were discussed. IoT analytics is at a nascent stage of development and its true value is yet to be fully realized. In the near future, the market for IoT and data analytics will further expand in different industry verticals.

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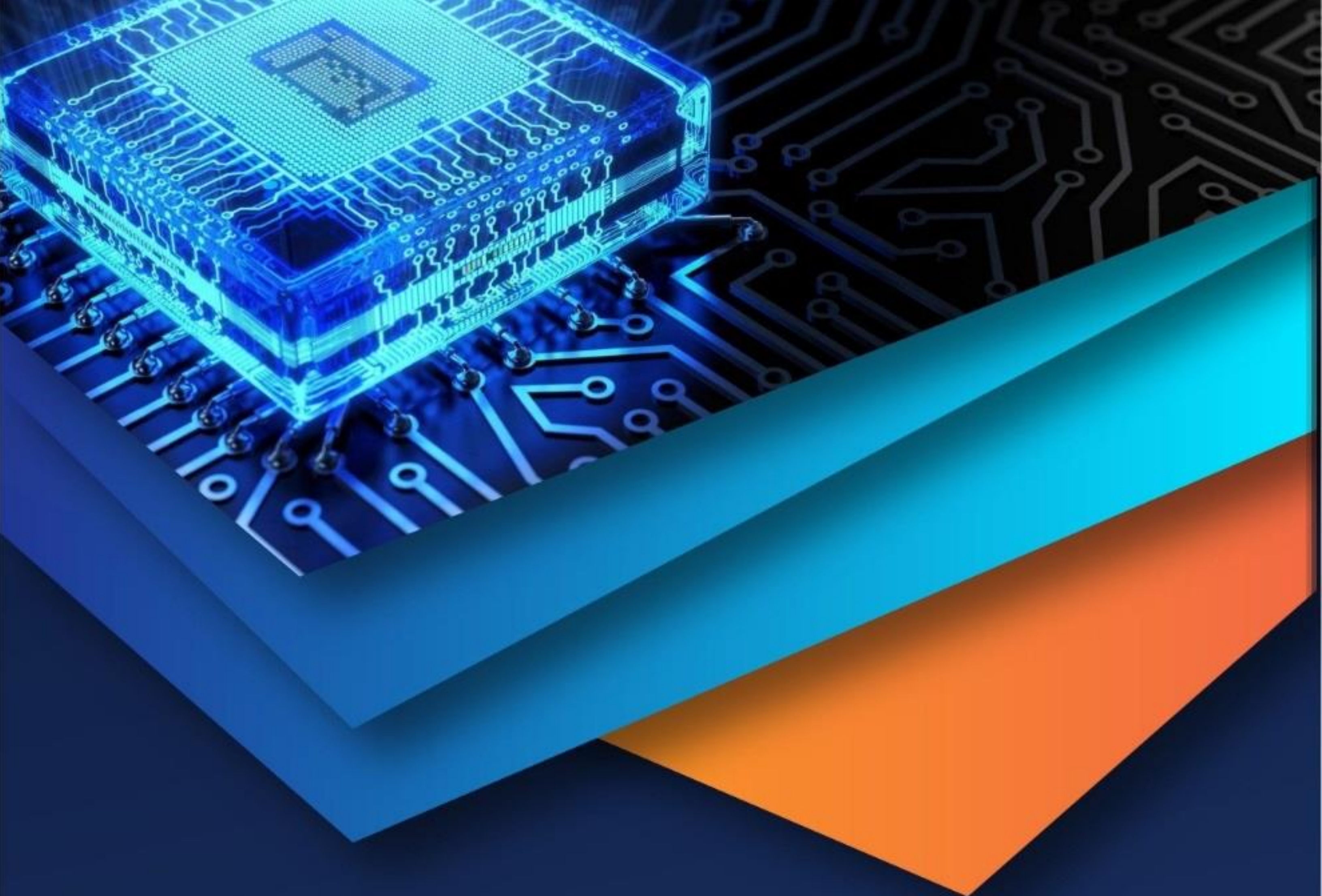

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