International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 10
***Article Received:** 26 August 2023 **Revised:** 20 October 2023 **Accepted:** 02 November 2023*

Industrial Internet of Things: An Analysis of Emergence, Component and Challenges

Reena Hooda[1], Ajay Kumar[2], Shivani[3], Sudhir[4], Pooja[5], Partibha Yadav[6]
[1]Department of Computer Science
Indira Gandhi University Meerpur, Rewari
Haryana, India
E-mail: reenah2013@gmail.com
[2]Department of Computer Science
Indira Gandhi University Meerpur, Rewari
Haryana, India
E-mail: yajay2@gmail.com
[3]Department of Computer Science
Indira Gandhi University Meerpur, Rewari
Haryana, India
E-mail: shivanigupta646@gmail.com
[4]Department of Computer Science
PGT, Board of School Education, Rewari
Haryana, India
E-mail: sudhir.yadav984@gmail.com
[5]Department of Computer Science
Indira Gandhi University Meerpur, Rewari
Haryana, India
E-mail: poojay220@gmail.com
[6]Department of Mathematics
Indira Gandhi University Meerpur, Rewari
Haryana, India
E-mail: pratibha1007@gmail.com

Abstract— Industry 4.0 brought a solution to disrupted industrial manufacturing powered by AI, machine learning, IoT, Cloud Computing, and Wireless Technologies. The factories turn into smart industrial units where the processes are automated, self-reliant, continuously monitored, and scaled as per the observed conditions. The Industrial Internet of Things (IIoT) solves the issues by real- time decision making or even alarming the hazardous situations say breaking down of systems or processes based on predictive analytics. From the raw material to the customer satisfaction the whole production line turns intelligent making the production fast, quality-based, well maintained, monitored, and innovative. The 3D printing, simulation, and augmented reality encourage innovations, designing & testing of customized products in the virtual environment. Big data analytics and accurate prediction not only foster manufacturing quality & quantity but also attracts high-valued staff with increased efficiency. Getting trustworthy data in real-time and eliminating life hazards in monitoring the typical processes are the key attractions of Industry 4.0 for instance, IoT with different kinds of sensors replace human monitoring and even performs well where the humans cannot go like the radioactive, humidity pressure. The product is tested well, safer to use, and promoted to the areas predicted by the advanced computing algorithms in data analytics. However, emerging technology can pose challenges for employers in a country where unemployment exists. So technological advancements, training, and skill developments are urgent areas to look after. This paper presented literature survey focuses on the major components, characteristics and associated challenges of Industrial IoT.
Keywords —Industry 4.0, IIoT, Cloud Computing, IoT, Sensors I

I. INTRODUCTION

Industry 4.0 word introduced by the German government in 2011 as a initiative program to enhance the efficiency in manufacturing industries. The terms such as industrial IoT, industry 4.0, smart industry etc. are coined similar and described the core concept of advancement in manufacturing process in more optimized ways. The aim of this process is to exchange the useful information about the manufacturing process during the whole cycle [1].

Industry 4.0 transforming manufacturing into a smart supply chain starting from raw material sourcing to product distribution and customer satisfaction using smart technologies like IoT and communication (IBM), cloud computing, big data analytics, machine learning, and artificial intelligence throughout the operations. As per the definition given by the website of i-scoop "Industry 4.0 is the digital transformation of manufacturing/production and related industries and value creation processes" [2]. Industry 4.0 is the digital transformation of the manufacturing or the production, making a factory smart through the digitalization of work lines, featuring a new phase in the data driven industry. Inbuilt software in the machines, edge computing help in collecting data and doing analysis to make smart decisions. The machine learning and AI technologies including the IoT tools introduced smart benefits like increased automation in the processes, accuracy, timeliness, critical monitoring, self-reliance, predictive maintenance as well as future projections (IBM) to optimize the manufacturing process and support customized manufacturing with 3D simulation for designing & testing of the product as well as different processes of assembly lines[3]. Industry 4.0 is the fourth revolution in the manufacturing and service industry. Different IoT sensors incorporated in manufacturing produce a huge amount of data regularly that is analyzed by the complex computational algorithms at the edge level as well as a cloud. The data analytics and process monitoring can be done from anywhere with the use of sophisticated cloud applications and monitoring services in a secured way.

In industry 4.0 implementation IoT required multiple devices, sensors and machines to connect with a central network to reduce the downtime and enhance the manufacturing process [4]. The IoT devices relate to each other to make a continuous monitoring on production process. It uses sensors for temperature, pressure, and humidity tracking while the connected devices provide information about the status in real time manner. The information produced by these devices are analyzed by artificial intelligence techniques to optimize the process or identify useful patterns. It can help to reduce downtime, optimize the process, and save production costing [5]. It can also help to alert workforce to ensure targeted safety hazards and prevent injuries and accidents for the workers. In this regard safety management system are introduced by the researchers [6]. The focus of this systems is to design a real time personal protective system. The system used mesh network architecture for information transmission, and a body area network to ensure the worker security. The developed system used RFID modules as a protective equipment. Lee et al.,[7] introduced a IoT system perform real time worker tracking in hazardous areas in construction site to prevent fall injuries. Other than these, the IoT devices can also be vulnerable against cyberattacks, which can breach the integrity of the manufacturing process and put sensitive information at risk. Different IoT devices use different protocols for communication which make it difficult to combine into a cohesive system. IoT sensors in network can generate high volume of data, which can be overwhelming to analyze and manage. The implementation of Industry 4.0 required several constraints for implementation. In this, large investment, advanced technology structures, and infrastructure are one of the main constraints needs to be considered. It is exceedingly difficult for the small businesses to adopts industry 4.0 with their fewer resources [8]. Industrial-IoT system is a subset of IoT that required higher safety and security for reliable communication without any disruption of industrial operations in real time manner. The IIoT focused on efficient management of industrial operation and assets along with predictive maintenance. The evolution in IIoT system expected in future enable Industry systems to narrow the organizational gap between human and machines. In this study the authors presented a review provide the insights about adoption of IoT in the industry management. The paper has also discussed about the application of IoT in industry evolution, foundation of IoT system used for industrial implementation, technologies used in smart industrial management, and also gives a broad discussion about different challenges associated with the implementation. The paper attempts to find out the possibilities for Industry 4.0 implementation and what provisions should be made to best utilize the different resources, and human expertise to avoid the loss of their lives in complex operations as well as to maintaintheir jobs academically.

II. DIFFERENT INDUSTRY REVOLUTIONS

The first industrial revolution was started in the 18th century in Britain that used steam engines and machines to increase production replacing handmade items. The second revolution came with the oil or gas- based engines along with electrical apparatuses in the manufacturing processes, telecommunication facilities, and automated assembly lines of production (IBM). In the second industrial revolution, the globalization of the business was started and other services like water supply gas were adopted publicly. The third industrial revolution started in the mid-20th century when the data analysis and advantage of computing powers started to automate the machine. Other additional backbones of the third industrial revolution were the introduction of robotics, developments in the field of technology like the internet, information & operational technology, and digitalization of machines, networking, and the spreading of the electronics business. Data Collection, storage, and analytics with high-level programming languages started in this century and are now the fourth Industry revolution that merges the high-powered computing technologies and web-enabled automated devices in creating a smart assembly line and facilitates the supply chain management, real-time decision making from anywhere around the globe.

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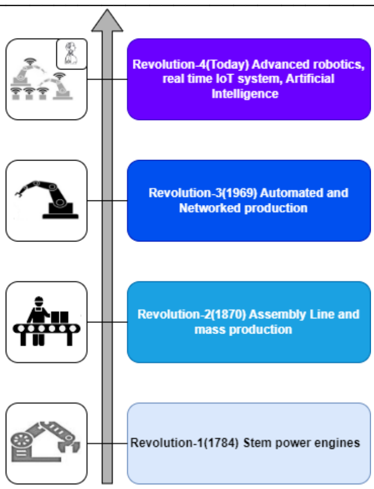

Figure 1 Industry Revolution Timeline

Though machine automation, digitalization, and the use of the data computation methods started in the industrial revolution third; in the industrial revolution of fourth, these tools & techniques became more advanced with the use of machine learning, artificial intelligence, big data analytics, IoT devices with IP addressing, wireless connectivity, cloud computing making the factories smart and provide the cyber-physical control with embedded controlling apps for the remote control as well as the virtual reality & simulation platforms for drafting and testing [9-10]. The industry revolution timeline is also illustrated by the figure 1.

III. COMPONENTS OF IIOT

AI and machine learning-based digitalized equipment, automated work lines with grid computing, solar energy, and various IoT devices, big data analytics, huge storage capacities, ad hoc communication technologies like wireless sensor networks, mobile ad hoc networks, etc. are the major building blocks of the IIoT [11].

A. *Internet of Things*

IoT inbuilt sensors used in machines at the field level have unique IDs and wireless communications to other devices [12]. These web-enabled devices gather & transfer the data for analytics, decision making as well as monitoring. AI and machine learning with sensor data, edge computing on data gathered from in-house resources plus from the cloud and from other business data to make the predictive decision making. IoT is the core of Industry 4.0 and IoT devices plays a significant role in developing a smart ecosystem in the factory. Sensors and actuators are used to interact with the environment and control the physical objects or operations, processing & transmitting data over the network. Sensors collect data about an environmental condition or happening activity and record the status of an action taken for which they are mounted in that area. The environmental condition may involve the humidity and penetration of air, pressure during testing and working in the workshops, assembly lines, fluid/water levels, flow in the water pipes, scarcity of raw materials in the godowns, effects of various chemical reactions, the flow of air & moisture, etc. Sensors and actuators can be connected in wireless or wired transmission modes in a Local Area Network (LAN in a small distance) or closer in a Personal Area Network (PAN) like Bluetooth. There is not any specified standard for the organization of the devices like set-up, mounting, and usability of sensors; they are deployed as per the factory requirements and of course the budget. Sensors can be Global Positioning System (GPS), Electrochemical, Gyro, Remote Flammable Detector (RFD), Light Dependent Resistors (LDR), Tensiometers, Solid State and Volumetric for soil moisture, Proximity Detectors, Pressure Transducer/ Piezometers, Motion Detector, Infrared (IR).

B. *Edge and cloud computing*

It helps the business to grow by providing useful information on various parameters. Business data with cloud-based services assist in finding new business segments and opportunities for their marketing and growth. Data Analytics and sharing of resources on an ad-hoc basis minimize the purchase cost of the devices as well as support easy scaling of the business at a lower cost (IBM). Edge computing makes it possible to collect data & computing at the service point and quickly respond to take real-time decisions rather than latency in transferring to the cloud and responding from the cloud. This way allows the minimum network load and enhances privacy as well as security with decreased latency time. IoT system allows to get the data from the physical world, transmit it and processed with help high processing units and algorithms. It continuously transmits the data from one layer to another layer and transform them into a useful information that help to build an intelligent network system in a broad range of scenarios (healthcare, smart energy, smart cities, etc.). The huge amount of data generated by the different IoT devices requires extremely high bandwidth and cloud services.

In this regard, edge computing techniques allows to filter the IoT Object at the network edges instead of transmitted it from the cloud [13]. This concept provides the faster services and reduces the turnaround time as compared the cloud computing services. In this regard, several architecture for industrial adoption of cloud computing are developed by the researchers such as FAR-Edge[14], etc.

C. *Big data analytics*

Continuous advancement in technologies enables companies to collect more and more high volume of data measured by zettabytes in 2020. It is the need of the hour to gather the useful information in the collected data. In this regard data analytics techniques can be utilized for the efficient advancement industrial environment. The data analytics approaches for IIoT classified into 3 categories: Predictive analytics, descriptive analytics, and prescriptive analytics. In predictive analytics, historical patterns are utilized to meet with the future assumption like that the historical trends and patterns are repeated themselves in same manner. It uses historical dataset and identified tagged attributes. These targeted attributed typically useful for the identification of future trends. It generally utilizes regression, Bayesian statistics, decision tree, neural network and etc.[15]. In this, prescriptive analytics helps to meet with the optimal plans trends in near future. It generally includes 2nd order cone programming, linear programming and semidefinite programming for result optimization. Descriptive analytics is one of the another analytics strategy that is very common and widely used for data analysis. It generally includes statistical measurement such as median, mean, skewness and mode. But the impractical assumption is one of the major issues in these measures. Therefore, this analytics used clustering to search hidden pattern and association rules used to find the object connections [16].

D. Network security

Network security is another major component because the cyber bomb is the greatest threat to the industry as well as the web-enabled economy so field level machines must be safeguarded from the outer web attack and the data safety between the edge and cloud even within the cloud storage (IBM). In this regard, different security standards are required to validate the security solutions and mechanism to validate a secure IIoT network. In a positive effort that how to develop, deployed and improve the IIoT network, the Industrial Internet Consortium was formed that detailing a standard method for secure IIoT network implementation. The aim of the industrial internet consortium is to design a security framework that widely applicable for industrial network implementation [17]. The IEEE 1934-2018 standard also known as OpenFog Reference Architecture developed by the researchers, which is capable to ensure the interoperability in secure system. It also helps to reduce the latency in response time and support processing at the edge of the network. Network security in IIoT generally focus on integrity (data modification during the transmission between the nodes), authentication (pretended identity of data source), privacy(identification of users are non- traceable), Confidentiality and availability(services are available for legitimate end users)[18-19].

E. Communication Protocols

Gathering of data ("data acquisition") and transmission to the high-powered cloud efficiently requires high-speed connectivity between different networks and linking an area like an office, field, or home to the Internet for proficient data exchange, and protocol conversion between heterogeneous networks is done by this component. In loose terms, a router can act as a gateway and for an enterprise network, a firewall performs the task of gateways. The network can be a local area network for example "wireless fidelity" (WiFi) or a wide area network like a "global system for mobile communication" (GSM) or the "5th generation mobile network" (5G) or the wireless sensor networks (WSM) and mobile ad hoc networks etc. In this regard, Meng et al., proposed a ZMQ model for flexible machine to machine messaging transfer for data sharing. The proposed research was experimented on food manufacturing quality inspection. It concludes that the ZMQ model is a efficient tool for machine connectivity. It showed that the proposed model solve heterogeneity problem and allows cross platform connectivity [20]. T. Qiu et al.[21] introduced a synchronization mechanism known as R- Sync. The proposed scheme was capable to established node synchronization with less energy consumption after elimination of isolated nodes. The scheme used two timer for node synchronization. In this one timer used message exchange for synchronization and another timer used is used for beginning. The inventor of the scheme was also introduced an algorithm to select a root node for efficient energy management. P. Ferrari et al.[22] conducted a study in which the authors investigated the MQTT protocol latency for observing the total round trip time for data transfer between clouds to back. The author used a embedded system for the experimentation and observed that the experiment produced less latency].

IV. ARCHITECTURE OF IIOT

Figure 2, shows the basic architecture IIoT in which the first layer represents the interaction with various data sources in collecting a vast amount of data of different nature. What data is to be collected, when to be collected, and in what frequency is the task of the first layer in which the sensors and actuators are operated as per the control commands. The sensors used in IoT can be standalone or can be embedded in other devices to monitor and collect data at different intervals frequently based on conditions or triggering of an event or at regular intervals. Data collected by sensors is raw data, structured & unstructured stored in a big data warehouse considered a "Data Lake" as data is massive and variant ([IBM).

Actuators act after the happening of a new event or when the given condition is true as per the commands from the decision unit based on the historic data as well as the input received. Actuators perform automatically without human intervention, like closing the pipes when watering is sufficient, painting a product with defined intensity, triggering the signal when oil or the electricity level is below the marked level in storage tanks, or lighting off or on, etc. as commands given by the control applications. The commands

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can be stored in the big data warehouse, automatically selected based on the condition, and directed to actuators to perform a task. The commands are divided into two parts, one is rule- based that are oversaw by the edge and the others are machine learning-based controlled in the cloud for complex parameters and new inputs (IBM). In the first layer, data is not only collected but also shared among the various devices in wireless sensor networks to monitor the events and machines for a robust system that can work in the failure of any part. The second layer is the data gathering layer that acts as a mediator between the less capable devices to the cloud i.e. highly capable and core of IoT. This layer manages the devices, acquire data from sensors, store data and preprocess before transferring it to the core. This layer selects only the useful data from the vast amount of data recorded by sensors, encrypts it, and transmits it to the next layer. The flow of information is bidirectional in this layer. The gateway can be built with Raspberry Pi or Arduino, the difference between the two is that Arduino is based on a microcontroller board with strong I/O capability to control the hardware directly, simple, and good for repetitive tasks like the closing of lights, motor control, etc. Gateway provides data security in transmission. (Wikipedia, Rajiv). Between the second and third layer is the edge control, and it is closer to the sources of the data generation and minimizes the data to be transmitted to the cloud. Edge can take rule-based decisions while releasing the cloud for complex decision-making. Only data that data requires the power of the cloud in data analytics is transmitted, the rest is kept at the edge to utilize the bandwidth at maximum and to avoid latency time in data analysis and decision making. The mode of communication is real-time and bidirectional. Cloud is the core of the IoT storing the fragmented data (data generated from different sensors via gateways to the cloud) in a single place and performing the data analytics, predictions using sophisticated machine learning algorithms providing the outputs to the user on their dashboards and via notifications, also give recommendations to the user or the manager with a facility to overwrite the cloud recommended actions. It is a big data center that collects store, and analyze data in real-time and provide information to the officials through different applications on the environmental conditions, pressure or temperatures, abnormal events like machine or tools corrosion, or the data on predictive maintenance, etc.

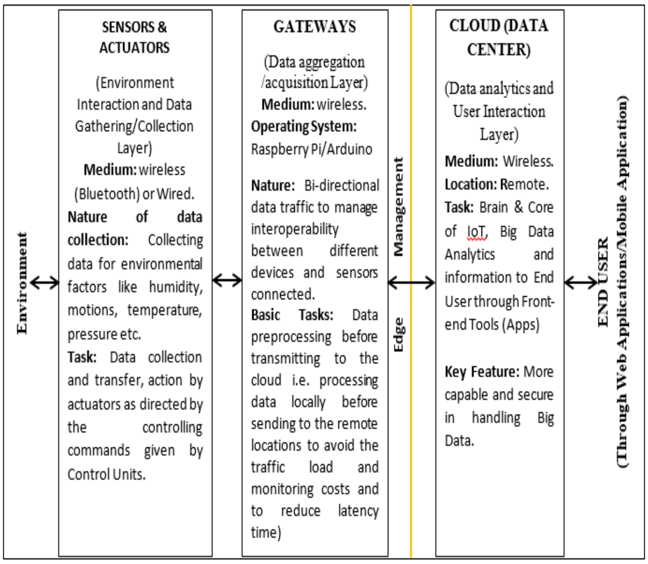

Figure 2: IIoT Architecture

V. CHALLENGES

The complex structure and requirement of other resources for the implementation of IIoT system have brought many technical as well as social challenges. Herein some challenges associated with the implementation are discussed such as:

A. Efficient Data Management

Management of continuous generation of high-volume data by the heterogeneous devices. The generated data by the smart nodes or devices are stored on heterogenous devise, gateways, edge servers, and cloud servers for real time processing [23]. In this process, data transmission, processing and storage is one the biggest challenges required high end efforts. To cup or tackle these issues an efficient data management system has been required for efficiently data handling with high speed processing.

B. Communication between different IIoT system

The IIoT system may be used different collection of devices and technologies for implementation. The IIoT system can be implemented with the help of different vendor technologies and used different industrial standards. It may be used different network for connection may be wired or wireless (5G, WiFi). Cross communication between these different vendor technologies be also a challenging task[21]. Multiple factors such as synchronization, data and resource sharing, data privacy and interoperability make communication more challenging between IIoT networks.

C. Data analytics

To getting the optimal results and full benefits of collected data, some flexible and robust analytical tools are required. The traditional database management strategies and tools are not enough to produce hidden trends as these tools are unable to manage high magnitude of data generated by diverse sources[15]. Other than these to analyze the Industrial data in real time is also a critical task. IIoT required real time data analysis for automation, prediction, production management, anomaly detection and down-time reduction. Therefore, to meet with the desired results some efficient and robust real time data analytical tools are required for data processing generated by the sensors.

D. Consumer trust and Industrial acceptance

The acceptance of technology by the industrial stakeholders is directly influenced by the technological trust factors. The deployment of advanced technologies in industry are infancy. In this regard, various recent research highlighted the privacy and security issues related with the successfully deployment of IIoT systems. It is also directly linked with the trust issues of their stakeholder. Thus, lacking privacy and security in IIoT deployment will discourage the stakeholders from the adoption of these technologies. Other than this, the consumption of power by the sensors and paid computing services also big issues in acceptance [24].

E. Centralized computing environment

The massive production of data from different heterogeneous sources continuously required the availability of network, storage and computing services. In this, cloud computing services provide the platform for data management and analysis via centralized controllers. This centralized dependencies increase the requirement of higher communication channels for communication [25]. Much recent research demonstrates that a single failure in centralized communication channels may lead the failure in whole industrial system.

F. Safety constraints

Safety constraints in case of any emergency and catastrophe should be highly recommended in IIoT system. In case of any state of emergency the worker's safety is one of most prominent tasks. IIoT system should require timely event detection, alert generation, notification of emergency and site localization with real time response time and provide needful management of fire, ambulance, police, traffic and other law enforcement. However, the absence of safety constraints in IIoT infrastructures is one of the bigger issues due to communication systems.

VI. CONCLUSION

IoT is the core of Industrial 4.0 revolutions provides transformation in production or the assembly lines with continuous monitoring and data collection physically as well as remotely by the cloud applications. The inclusion of edge computing in industrial operations facilitates prompt reporting, decision making, and predictive maintenance in real- time with reduced latency time in data travelling between the physical locations and the cloud. Cloud services help in big data analytics about the various business possibilities and provide flexibility in the business as per the market and global requirements. So, the scope of the IoT in industries is huge. This literature successfully demonstrated the prior research and services used for IIoT deployment. The authors also categorized some related challenges associated with the IIoT for future research. Industrial revolution has the capability to aid industries in their growth, the human workforce in their operations as well as support to find the new scope for the industries to protect the human artistic abilities.

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Dr. (Mrs.) Reena Hooda is presently working as Assistant Professor, Department of Computer Science & Engineering, Indira Gandhi University, Meerpur (Rewari). She earned her Master Degrees of MCA and MBA from MDU Rohtak and also Doctorate in Computer Science & Application from the MD University. She has also successfully completed the Data Science programs from Harvard University (USA) and Machine Learning & Data Analysis programs from IBM. She has been into teaching since 14 Years and served many reputed Institutes. Her areas of Interests focused at Machine Learning, Data Science, and Data Warehousing & Mining. She has successfully supervised more than 50 Major Projects of MCA and currently guiding 4 Ph. D. scholars at IGU Meerpur. Dr. Reena has published more than thirty papers in the national and international journal and fourteen chapters in edited book

Dr. Ajay Kumar is presently working a faculty member in Department of Computer Science & Engineering, Indira Gandhi University, Meerpur (Rewari). He earned his Master Degrees of MCA and M.Tech(CSE) from MDU Rohtak and also Doctorate in Computer Science & Engineering also he has UGC NET qualifed. He has 13 Years of teaching experience and served in multiple reputed Institution and University. His areas of Interests focused at IOT and Theory of Computation. He has successfully supervised more than 25 Major Projects of MCA at IGU Meerpur. He has been actively participating in various seminars, conference and also delivered many expert lectures. He has also published multiple research papers in national, international and reputed journals. He has received certification in Cloud Computing and Internet of Things from NPTEL

Dr. Shivani is currently working as a faculty member in Department of Computer Science, Indira Gandhi University, Meerpur, Rewari. She earned her Doctorate degree in Computer Science from Glocal University, Saharanpur, U.P. in 2023 and completed her M.Tech in Computer Science from Vaish College of Engineering, Rohtak, Haryana in 2015. She has successfully supervised more than 20 Major Projects of MCA. She has two papers in her credit in International Journals. She has been actively participating in various seminars, conferences and workshops. She has research interest in neural network, data mining, data science, machine learning etc.

Dr. Sudhir is currently working in Haryana Education Department as Lecturer of Computer Science. He obtained his engineering degree from Maharishi Dayanand University and he obtained his PhD in cloud computing and big data related research area. He has qualified both NET and GATE examination. He has helped many students in their projects. Apart from many prestigious institutions he taught as a faculty member in Indira Gandhi University, Meerpur, Rewari for about seven years. During his tenure, he made the student work on the latest technology like making live projects on Machine Learning and Internet of Things. Paved the way for children's projects on topics like Artificial Intelligence, IoT. He has received Elite category certification in Cloud Computing and Internet of Things from NPTEL.

Mrs. Pooja is currently working as a faculty member in Department of Computer Science, Indira Gandhi University, Meerpur, Rewari. She completed her M.Tech in Computer Science from Mody University Rajasthan in 2016. She has more than 6 Years of teaching experience and served in multiple reputed Institution and University. She has successfully supervised more than 20 Major Projects of B.Tech(CSE). She has also published multiple research papers in national, international and reputed journals. She has been actively participating in various seminars, conferences and workshops. She has research interest in image processing in AI etc.

Dr. Partibha Yadav presently working as a faculty member in Department of Mathematics Indira Gandhi University, Meerpur, Rewari (India). She had graduated her Ph.D. in Computer Science from Indira Gandhi University, Meerpur, Rewari (India). She holds M.Tech. in Computer Engineering and have about 12 years of teaching experience. in reputed College/University. She has about a dozen of published research papers/attended conference.