IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

A STUDY ABOUT APPLICATIONS AND CHALLENGES OF INTERNET OF THINGS ARTIFICIAL INTELLIGENCE AND DIGITAL TWIN

[1]Vandana Malik [2]A.J Singh

[1]Research Scholar [2]Professor

Computer Science Department

Himachal Pradesh University, Shimla, India

Abstract: Twenty first century is considered to be the age of information technology and evolution of technology is fast and inevitable. We have moved into Industrial Revolution 5.0 and technologies like Internet of Things (IOT), Artificial Intelligence (AI), Digital Twin (DT), Big Data and Blockchain are its building block. Through this article we have tried to understand how artificial intelligence, digital twin and Internet of Things are changing the world. IOT AI and DT are being used in applications like agriculture, manufacturing, health care, smart cities, smart grids, automobile industry, education etc. Self organization and maintenance of IOT and DT environment is the key to develop a reliable and robust system. A self organized system is self sufficient with the ability to analyze and take optimal decisions. Self organized system also takes care of energy utilization, management of huge amount of data generated by IOT AI and DT infrastructure. Self organized systems are vigilant and proactive against intrusions and cyber attacks.

Index Terms - Internet of Things, Artificial Intelligence, Digital Twin, Self organization and Industrial Revolution 5.0.

I. INTRODUCTION

Industrial Revolution 5.0 is another name of modernization, atomization, human machine interaction, green energy and sustainable development. Everything around us is connected to internet from home appliances to complex space missions. Real time data is collected from these things and after processing that data, important decisions and strategies are made. [1] Today, need of the hour is to build a self organized and self adaptable system which can modify itself according to circumstances without human intervention. Artificial Intelligence, Digital Twin, Machine Learning, Cloud Computing, Blockchain Big Data etc. are few enabling technologies which are used in Industrial Revolution 5.0. They help in building smart, self organized, self adaptable, autonomous systems with capabilities of real time data analysis, predictive maintenance, decentralized decision making, interoperability and connectivity between machines, devices and systems where humans and machines can coordinate to make Industrial Revolution5.0 a success. Through this study we have tried to understand IOT and its applications, how AI is empowering IOT , Digital Twin and its significance ,Self organized system and finally observations made through this study are highlighted.

II. INTERNET OF THINGS (IOT) AND ITS APPLICATIONS

Kevin Ashton (Father of IOT) used the term IOT for the first time while working in Auto-ID Laboratory at MIT in order to optimize the supply chain by using RFID (radio frequency identification). [2] Since then IOT has evolved massively and have reached our homes and touched our lives. IOT is a network of embedded devices and things like computers, mobile, laptops, sensors, cameras, wearable's, home appliances, vehicles, medical devices etc. which are connected to each other and internet. They have the ability of tracking, monitoring, recording, collecting real time data and sharing it with anyone, at anytime and from anywhere. [3] Data from these devices are collected through sensors, actuators and transducers. (Sensors measures temperature, pressure, humidity, smoke level etc. Actuator controls the mechanism of the system likes electric, hydraulic, thermal, magnetic and mechanical. Transducer is a combination of sensor and actuator). They all helps in gathering data from their surrounding and provide it for further analysis. IOT is being applied in the field of agriculture, supply chain and logistics, health care sector, development of smart cities, smart transportation, home automation, smart grids, smart environment etc. [4]Architecture of IOT is developed according to application and problem which it is catering. There is no standardized IOT architecture which is followed globally. Therefore IOT architecture should be flexible, ubiquitous and support heterogeneity. There are three layer, four layer and five layer architecture according to the requirement of IOT network.

Five Layers Architecture Business layer: is responsible for user privacy, complete management of the IOT ecosystem of the business. Application Layer: Application specific services are provided by application layer of IOT. In smart homes, smart cities, and smart health application layer behave according to the services it is catering. Processing layer: Middleware layer Data from transport layer is managed, transformed, analyzed and processed here. Technologies such as databases, cloud computing, and big data processing can also be incorporated. Transport Layer: Transfers the sensor data between perception layer and the processing layer. Networks like wireless, 3G, LAN, Bluetooth, and RFID are used. Perception Layer: Sensors are used for gathering data. [5]

2.1APPLICATIONS OF IOT

IOT is being utilized in multiple fields like Agriculture, Health care, Education, Transportation, Smart cities, Smart grids, Manufacturing, Home automation , Supply Chain and Logistics [4]

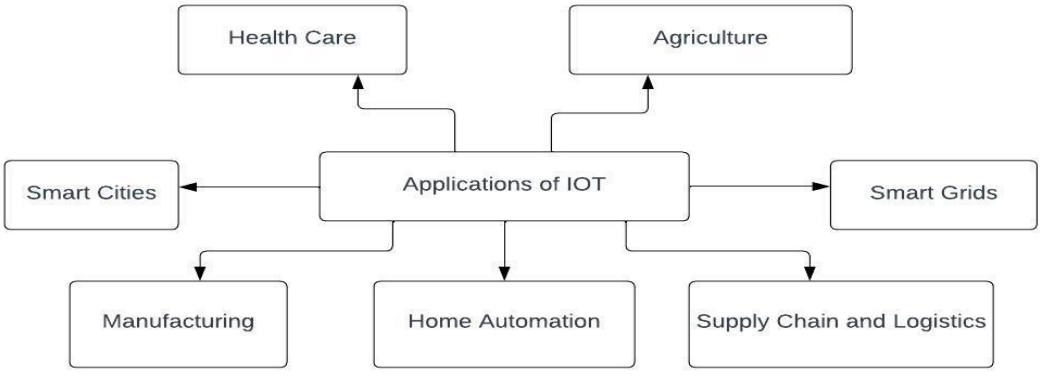

Fig.1 Applications of IOT

2.2CHALLENGES OF USING IOT

Heterogeneity: Different types of devices generate different types and volume of data, there are different methods to handle data. Interoperability: absence of universal standards for architecture and communication across heterogeneous environment leading towards interoperability issue between devices in IOT environment. Interoperability can be of different types like technical, syntactical, semantic and organizational. Need of routing algorithms for IOT which are efficient, energy saving, can adapt to scalability and improve performance. Security issues are prevalent in IOT so there is a requirement of

data protection mechanism which can enhance security of sensitive information like banking details. Billions of IOT devices generate enormous amount of data in ZB (Zettabyte) which is generated across the network therefore big data techniques, data science, cloud computing and data mining techniques should be developed for efficient use of data. *Limited energy and power supply* becomes an issues for the sensors who are battery dependent. In remote location batteries cannot be replaced frequently therefore energy efficient devices needs to be developed. [6]

III. AI EMPOWERS IOT APPLICATIONS

John McCarthy used the term Artificial Intelligence in 1956. Since then AI has shown tremendous growth and now its presence can be seen in multiple sectors like medicine, education, transportation, manufacturing industries, entertainment scientific research and defense sector. Intelligent machines have the ability to make best decisions on behalf of humans [7]. Internet of Things and Artificial Intelligence both are prominent technology in today's day and age. Technologies like face recognition, voice recognition, object detection, natural language processing are being incorporated into applications for enhancing performance and building secure, smart, intelligent and efficient infrastructure [8].AI helps in managing and extracting meaningful information from data generated by IOT environment because manually it's impossible to analyze huge amount of data. Prediction of data can be made from the analyzed data which can be beneficial for the business and industry.AI can also help in formulating policies and strategies based on the data analyzed. [9] AI eliminates the occurrence of human error, prejudice and biases from the system during data analysis. As AI limits human discretion, rules are followed properly which helps in keeping a check on any corrupt activity taking place in the system [10].

AI-IOT empowered Agriculture sector: combination of AI and IOT helps in reducing the time taken for sowing and harvesting of crops and reduces labor cost by using automated machines. In precision farming AI can help in making analysis over exact amount of water, fertilizer, pesticides, temperature etc. required for enhancing yield. Algorithms can be designed for irrigation management. Data generated by sensors are analyzed and it helps in making decisions. Drones can be used for the purpose of monitoring and spraying fertilizers [11].

AI-IOT empowered Health Care Sector: AI and IOT helps in developing smart health care infrastructure. Real time monitoring helps in observing changes taking place in the patient's body, provide proper diagnosis, suggest suitable treatment, medicine facilities for fast and speedy recovery of patients [12]. Telemedicine is a boon for the people living in remote areas where health care facilities are not available. Now patient and doctor can be at different locations, still patient can be treated with the help of technologies like IOT where cameras, sensors, wearable devices, mobile phone etc helps in generating useful data about the patient [13]. On the other hand AI helps doctors to analyze patient's health history along with present condition and data is processed and essential information is extracted from the data. Robotics can help in taking care of patients. During the era of COIVD-19 where social distancing were the norms automated testing, virtual meeting with doctor were conducted in order to keep heath care workers safe from getting in contact with SARS-COV-2 . Drones were used to disinfect and sanitize area regularly. IOT buttons were used to inform authorities to provide particular service in the area [12]. Technology has made heath care facility accessible and affordable. IOT and AI also help in material management, medicines and vaccines stock keeping, medical devices and equipments maintenance etc [14].

AI-IOT empowered Industrial sector: IOT and AI have revolutionized the way industries work. Robotics has improved manufacturing sector by embedding intelligent sensors into the machine and machines generate real time data. Based on the information plans and strategies are made for businesses. Real time tracking of inventory, maintenance of supply chain is made possible [3]. IOT and AI also help in developing relationships between customers, retailer and suppliers. Personalization of shopping experience and recommendation are given to customers while purchasing things. Market demands and trends can also be predicted by using AI [15].

AI-IOT empowered Education: Education is highly significant and an important pillar of modern world. Where minds are trained and awakened to understand various natural phenomena which take place on the earth. Scientific, social, economical, political, mathematical studies are done all around the world. With the help of AI, augmented reality, virtual reality and IOT children can study in more interactive way. Where children can experience different phenomenon that enables fast learning, develop communication skills and it can also enhances retention power of children. AI helps teachers in

maintaining, monitoring and analyzing student performance in class. Details about where children are lacking, what difficulties they are facing while studying can be observed and children can be helped and assisted accordingly [16]. During pandemic in 2020 and 2021 online learning became new normal for education sector. Classes, exams, seminars, viva, interviews were conducted online in order to maintain social distancing and to stop the spread of virus. AI and machine learning algorithms were used to perform administrative tasks and paper evaluation [17].

AI-IOT empowered smart cities: as the population is increasing day by day cities are getting over burdened and face huge resource crunch and it is getting difficult to sustain huge population. Therefore smart and innovative design and architectures are required in order to accommodate people in limited space in an efficient manner. Green spaces all around the cities are also required for fresh air and for maintaining temperature of the surrounding. IOT sensors deployed in environment can help in determining air pollution, noise pollution and temperature of the city [18]. IOT and AI can help in building smart and safe infrastructure. IOT devices like cameras, sensors and AI enabled technologies like face recognition speech recognition can improve surveillance of an area [17].Efficient use of parking space and automated traffic light control based on real time circumstances can help in traffic management and prevent accidents. IOT network enabled with AI can detect and report accidents taking place in remote location and help can be provided by the officials immediately [19].

AI-IOT empowered Smart Grids: Energy is an important resource so proper management is required. Automated power grids can help in managing energy losses. AI can be used for operating and controlling smart and safe electric power supply network. Renewable energy sources generating electricity transmission and distribution process can be monitored and managed by AI and IOT technologies [20].

AI empowered IOT Architecture: basically IOT architecture consist of three layer sensing layer, network layer and application layer. In sensing layer selective sensing can be done with the help of biological inspired algorithms and neural system. In networking layer AI can be used for choosing best routing algorithms, to optimize network scheduling, enhance quality of service, self organization of network. AI can be utilized for providing security at application layer [21]. High performance and reliability can be achieved by incorporating AI technologies and by limiting human involvement. At Application Layer AI can be used in diverse applications to personalize services according to user requirements. Decision making ability of a machine can be improved by utilizing huge datasets for training machines. Hidden information and patterns can be determined by data processing and using data mining methods on data generated by IOT devices [22] .

IV. DIGITAL TWIN AND ITS SIGNIFICANCE

Digital Twin is a virtual representation of a physical asset. All the dimensions, properties and attributes of the physical assets are represented in minute detail to achieve high fidelity in the digital twin model. DT is a simulating model where a real world entity or object is mirrored into its virtual form, where past present and future of the entity is under constant observation throughout its life cycle. NASA Apollo space mission is claimed to be the first to use twin concept. In 2003 Michael Grieves introduced the term Digital Twin to the world at University of Michigan in product lifecycle management course. Digital copy, digital avatar, virtual projection of the real product was created for observing its behavior in particular condition. According to Michael Grieves conceptual model of a digital twin consist of a Real space, virtual space and a proper connection between the two for communication and exchange of information. DT can be built for conceptual phase, design phase, manufacturing phase, operational phase, Post life phase and retirement phase. Foundation of Digital Twin are based upon Physics based model, Reduced-order Modeling where both physics based model and machine learning comes together to speed up the predictive computation of the system. Probabilistic Graphical model are used for building a framework for measuring and clubbing data for planning and controlling the activities of the system [23].

4.1 APPLICATIONS OF DIGITAL TWIN

Use of IOT and DT in similar applications can be observed and DT is capable of managing these applications. DT of any manufacturing industry, a factory floor or a DT of any machine can be created so that health of the machine and manufacturing process can be under complete observation. Based on the observation proactive steps can be taken which can beneficial for the business. For example if a machine is in constant use for a long period of time then its maintenance is necessary. DT of the same machine can be used for monitoring which parts of the machine needs to be replaced or repair without shutting down the entire business activity. Here DT is able to save the machine from a complete breakdown. Non working hours of the machine are also reduced by replacing machine parts when machine is not in use or its work load is minimal so that business activity do not get hampered. In an aerospace sector DT of space mission aircraft or defense missiles etc can be developed by using physics based model and incorporating mathematical and computational techniques to build a predictive digital twin. Use of DT in Urbanization and making Smart cities is becoming part of national interest. As people are migrating from villages towards town and cities it is becoming difficult for urban areas to handle such huge population. Therefore Smart cities are being developed where structure of the building to electricity connection to gas pipeline, surveillance cameras, water pipeline connection, traffic management in city etc. all are part of the DT which can help in maintenance of the city along with smooth flow of traffic . Similarly we can observe that DT is being used while constructing DT of civil infrastructure like highways, bridges, metro stations and railway lines. Digital twin is capable of planning, managing, maintaining and analyzing life cycle of the infrastructure being developed. International businesses have developed their DT which can track demand and supply of products all around the globe. All the factories and shipment being delivered to different locations are under constant observation through their DT so management knows beforehand which shipment will be deliver where and when, if any shipment is late they know it before hand and why they are late, what is the reason everything is known to the management so that business strategy can be made in order optimize their profit. Agriculture sector is not untouched by the Digital Twin technology. DT have the ability to predict weather conditions can based on that moisture content in soil irrigation can be done accordingly. DT can also predict if any natural disaster will take place and what impact it will have on the growth of the plants and their yield. DT of an agriculture field and market helps the farmer analyze his agricultural activities and yield which is produced can be delivered to the market where maximum profit can be earned. [24]

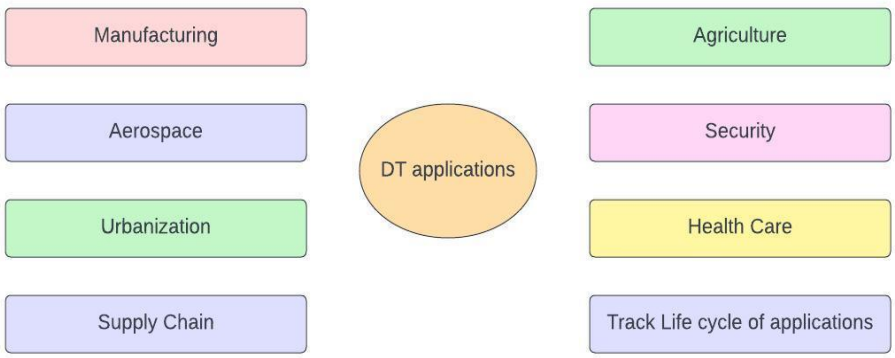

Fig.2 Digital Twin applications

Digital Twin can play a major role in security of system. Security orchestration automation and response (SOAR) with digital twin handles security tools and assets. SOAR4IOT framework integrates IOT devices security tools to protect system from Sybil and Mirai attacks. SOAR integrates, automates and streamline workflow of system for quick and appropriate reaction for an event or attack that takes place. IOT devices are highly vulnerable, sensitive and an easy target for any cyber attack because of heterogeneous devices being used in the IOT network which can easily be compromised and cause security threat. Default username and passwords of these devices can be hacked easily and botnets can be developed. DT helps in securing IOT from cyber attacks using SOAR framework for investigation and setting up proper react and course of action if any attack takes place. Automated playbook is developed for an efficient and optimal use of time and resources in the system. DT runs three operations

Replication (virtual replica of physical entity) simulation (model of real word entity in terms of user specific parameters) Historic data analysis (analyze IOT devise behavior in past and derive conclusion for future) [25]. DT applied in cyber security for anomaly detection, intrusion detection, prevention system and also helps in mitigation process. Cyber Physical Space Twinning, Cyber situational awareness framework are used for anomaly and intrusion detection. Purpose of DT in different phases of industrial applications are like in design phase iterative optimization can be done by evaluating performance which was predicted and the actual performance after constant improvement in DT system. . DT provides data integrity by processing data into meaningful information which can help stakeholders in decision making. Virtual evaluation and verification is also performed to reduce inconsistency between actual and expected behavior. During manufacturing phase real time monitoring, production control, asset management, production planning, prediction about performance, cooperative relationship between human and robot and finally evaluation of process and optimization are done by DT. In service phase Predictive maintenance, Fault detection and diagnosis, state monitoring, performance prediction are carried out by DT. In retirement phase DT keeps track of entire life cycle of application for future reference and can be used in remanufacturing of similar kind of product [26].

Tools used for implementing Digital Twins are commercial tools like DXC digital twin, Simcenter 3D, Bosch IOT Suite, Microsoft IOT services, Seebo digital twin, ANSYS Twin Builder and open source tools available are Eclipse Ditto and CPS Twinning etc [26]. CAD used for simulation and Python for analyzing occurrence of data [27]

4.2 LIMITATIONS OF DIGITAL TWIN

Digital twin have limitations like *scaling* because DT for micro level and macro levels are developed but in some cases like where cancer cells in human body are at micro level and DT is unable to represent infected cells onto the its digital version so its difficult to built super sensitive micro level DT with high efficiency. DT is *Inter disciplinary* field where expert of different fields are required to build high fidelity DT with high accuracy. Cyber security is another prevalent issue these days for IOT and DT infrastructure. For proper functioning of DT it needs to be *connected to internet at all times* for real time data collection, storage, processing and analysis. While creating system of systems smaller digital twins are combined to form bigger digital twin structures faces problem of *horizontal integration* in this same DT of a particular level is analyzed from different perspective and it causes problem of data integration at different levels. *Incompatibility* issue arises because of heterogeneity data generated by different types of devices at different levels of DT cause interoperability problem. *Intellectual property* behavior and services of DT can be considered as intellectual property therefore they need to be protected [27].

Digital Twin technology is incomplete without Internet of things and Artificial Intelligence. IOT and AI are key technologies along with machine learning algorithms, 5G technology and Big Data all are utilized to form highly efficient and robust DT.

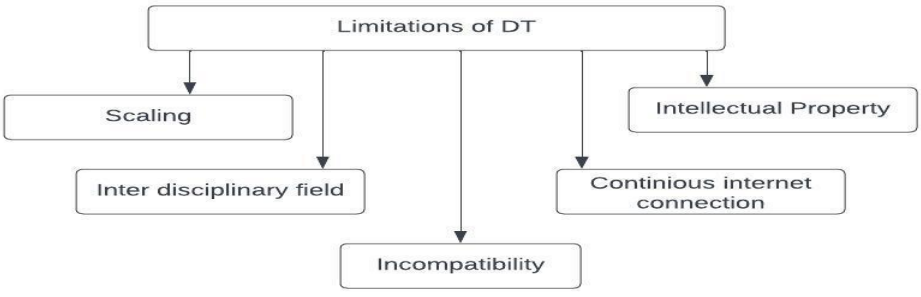

Fig.3 Limitations of DT

V. SELF ORGANIZED SYSTEM

Self organization is a concept which emerges when number of smaller subunits joins to form a large system. Self organization is ability of the system to perform some collaborative and coordinated course of actions in order to achieve some predefined global goals. Self organization is achieved when all the protocols and rules are followed while interacting and exchanging information between different subunits of the system. Self organized systems are considered to be reliable robust scalable and adaptive in nature. A well organized system is the one with the capability of self configuration, self management, self adaptability, self protection, self healing, self optimize and self diagnosis [28]

5.1 NEED OF SELF ORGANIZATION

Self Organized system achieves ability to make decision by them self without human assistance. IOT Network should be able to predict and recognize faults and handle them by responding in an organized manner [29]. Self Organization also helps in efficient use of resources and optimizes system performance. IOT is a decentralized network facing privacy issues along with quality of services [30]. Heterogeneity is a major issue that appears in IOT infrastructure at every level from variation in network topology, software, hardware and variation in data type, volume and methods to deal with data. Work needs to be done for finding harmony and a sweet balance between things to work in a heterogeneous environment [31] .There are different methods of achieving self Organization like Neural Network, Reinforcement Learning Base, Game Theory Based, Data Mining, Artificial Intelligence, Evolutional Theory Based, Swarm and Ant Intelligence (Bio Inspired) algorithms.

VI. RELEVANCE OF IOT AI AND DT IN INDIA

India is one of the biggest economies in the world with highest number of smart phone users. India has huge population of young people who are embracing changing trends and technologies. India is evolving, adapting, learning and transforming its society and its people with information technology. 70% of Indian population is dependent on agriculture and many urban cities and town are hub to service sector but there is huge potential for digital transformation and automation in India. Internet of Things, Artificial Intelligence and Digital Twin can make a huge difference many sectors by creating Digital Twin of urban India, smart cities, 3D mapping of India, Telecom sector can also utilize DT technology for proving better services to the people in fast and efficient manner. DT can be designed for renewable energy sector where solar power plants, wind miles, nuclear power plants, hydro power plants. So that energy can generated stored and transferred in a transparent manner. Management, maintenance and monitoring of power plants and smart grids can be done by using these technologies. Electric Vehicle charging stations and automated driving assistance can also be provided by IOT and AI. Economic sector can utilize these sectors by using machine learning and AI algorithms to identify need of customers and speed of product delivery can also be increased by using these technologies. Street vending activities can also be controlled and accessed which is part of unorganized sector. Disaster management activities can also be managed and level of disaster can be predicted before hand, warning can be given to local people to vacate the area and helps to plan mitigation process in order to prevent loss of life. Safety of workers in construction sites by using these technologies is possible, Indian government scheme named Pradhan Mantri Gati Shakti is working for the safety of workers at construction site by using 5G technology along with Digital Twin. Banking processes and property tax evaluation and collection processes can be replicated into its DT where all the illegal tax fraud can be caught and brought to court of justice. Border security is a prominent issue which can be resolved by AI empowered unmanned weapons with its digital twin who can conduct sophisticated attacks on their enemies [32].

VII. CONCLUSION

Through this study it has been observed that there is an overlapping of application areas of DT IOT and AI. IOT was improved by artificial intelligence and now digital twin technology has taken over, by providing simulation tools where even before actually developing any product we can analyze and predict how that product will work in different condition and learn about potential improvements which can be made through out its life cycle. DT and its physical counterpart communicate and DT gets updated, wear and tear taking place in any part of the machine changes the DT in real time so that correct decision can be made. India has a huge potential for digital transformation. As all the major cities of India are being converted to smart

cities therefore use of sensor technology like IOT, AI based applications and DT simulation can be seen in next few coming years. Digital Twin, augmented reality and virtual reality will change the way education is being imparted today. Experiential studies will transform education sector and entertainment sector. These both sectors will see huge growth in coming years. Internet of Things, Artificial Intelligence, and Digital Twin plays a significant role in order to achieve industrial revolution 5.0. Interdisciplinary research can help to build strong IOT, AI and DT applications for solving problems of the society. Evolution of technologies are providing unique solution to problems, helps in analyzing and predicting future and achieve efficient and optimal results from business processes. There are many areas like security and privacy issues still need to be resolved. Highly skilled labor and professionals are required who can deal with these technologies. In coming days we will see dynamic nature of technology which will keep on changing and evolving. We just need to be vigilant enough and open enough to embrace those changes and adapt accordingly to reap the benefits of these technologies.

REFERENCES

[1] Amr Adel, "Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas," *Journal of Cloud Computing*, vol. 11, pp. 1--15, 2022.

[2] Sridipta and Maheswaran, Muthucumaru and Hashmi, Salman Misra, "System model for the internet of things," in *Security challenges and approaches in internet of things*.: Springer, 2017, pp. 5--17.

[3] Kinza and Khawaja, Bilal A and Sabir, Farah and Qazi, Sameer and Mustaqim, Muhammad Shafique, "Internet of things (IoT) for next-generation smart systems: A review of current challenges, future trends and prospects for emerging 5G-IoT scenarios," *Ieee Access*, vol. 8, pp. 23022--23040, 2020.

[4] Abhishek and Kaur, Sanmeet Khanna, "Internet of things (IoT), applications and challenges: a comprehensive review," *Wireless Personal Communications*, vol. 114, pp. 1687--1762, 2020.

[5] P Ravi and Wan, Au Thien and Suhaili, Wida Susanty Haji Kumar, "Exploring data security and privacy issues in internet of things based on five-layer architecture," *International journal of communication networks and information security*, vol. 12, pp. 108--121, 2020.

[6] Tie and Chen, Ning and Li, Keqiu and Atiquzzaman, Mohammed and Zhao, Wenbing Qiu, "How can heterogeneous internet of things build our future: A survey," *IEEE Communications Surveys \& Tutorials*, vol. 20, pp. 2011--2027, 2018.

[7] Filip Karlo and Br, "Explainable artificial intelligence: A survey," in *41st International convention on information and communication technology, electronics and microelectronics (MIPRO)*, 2018, pp. 0210--0215.

[8] Jing and Tao, Dacheng Zhang, "Empowering things with intelligence: a survey of the progress, challenges, and opportunities in artificial intelligence of things," *IEEE Internet of Things Journal*, vol. 8, pp. 7789--7817, 2020.

[9] Yogesh K and Hughes, Laurie and Ismagilova, Elvira and Aarts, Gert and Coombs, Crispin and Crick, Tom and Duan, Yanqing and Dwivedi, Rohita and Edwards, John and Eirug, Aled and others Dwivedi, "Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy," *International Journal of Information Management*, vol. 57, p. 101994, 2021.

[10] Ninareh and Morstatter, Fred and Saxena, Nripsuta and Lerman, Kristina and Galstyan, Aram Mehrabi, "A survey on bias and fairness in machine learning," *ACM Computing Surveys (CSUR)*, vol. 54, pp. 1--35, 2021.

[11] Sameer and Khawaja, Bilal A and Farooq, Qazi U Qazi, "IoT-Equipped and AI-Enabled Next Generation Smart Agriculture: A Critical Review, Current Challenges and Future Trends," *IEEE Access*, 2022.

[12] Vinay and Hassija, Vikas and Gupta, Vatsal and Guizani, Mohsen Chamola, "A comprehensive review of the COVID-19 pandemic and the role of IoT, drones, AI, blockchain, and 5G in managing its impact," *Ieee access*, vol. 8, pp. 90225--90265, 2020.

[13] "Cognitive computing and wireless communications on the edge for healthcare service robot," *Wan, Shaohua and Gu, Zonghua and Ni, Qiang*, vol. 149, pp. 99--106, 2020.

[14] Shashank and Raut, Rakesh D and Priyadarshinee, Pragati and Mangla, Sachin Kumar and Awan, Usama and Narkhede, Balkrishna E Kumar, "The Impact of IoT on the Performance of Vaccine Supply Chain Distribution in the COVID-19 Context," *IEEE Transactions on Engineering Management*, 2022.

[15] Wayne D and Kroschke, Mirja and Schmitt, Bernd and Kraume, Karsten and Shankar, Venkatesh Hoyer, "Transforming the customer experience through new technologies," *Journal of Interactive Marketing*, vol. 51, pp. 57--71, 2020.

[16] Wei and Berestova, Anna and Lobuteva, Alisa and Stroiteleva, Natalia Wu, "An intelligent computer system for assessing student performance," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 16, pp. 31--45, 2021.

[17] Ram and Singh, Varsha and Aggarwal, Arun Gopal, "Impact of online classes on the satisfaction and performance of students during the pandemic period of COVID 19," *Education and Information Technologies*, vol. 26, pp. 6923--6947, 2021.

[18] Bhagya Nathali and Khan, Murad and Han, Kijun Silva, "Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities," *Sustainable Cities and Society*, vol. Elsevier, pp. 697--713, 2018.

[19] Fotios and Koulouras, Grigorios and Karabetsos, Sotiris and Kandris, Dionisis Zantalis, "A review of machine learning and IoT in smart transportation," *Future Internet*, vol. 11, p. 94, 2019.

[20] Zhongtuo and Yao, Wei and Li, Zhouping and Zeng, Lingkang and Zhao, Yifan and Zhang, Runfeng and Tang, Yong and Wen, Jinyu Shi, "Artificial intelligence techniques for stability analysis and control in smart grids: Methodologies, applications, challenges and future directions," *Applied Energy*, vol. 278, p. 115733, 2020.

[21] Feifei and Ning, Huansheng and Huangfu, Wei and Zhang, Fan and Wei, Dawei and Hong, Tao and Daneshmand, Mahmoud Shi, "Recent progress on the convergence of the internet of things and artificial intelligence," *IEEE Network*, vol. 34, pp. 8--15, 2020.

[22] Helin and Alphones, Arokiaswami and Xiong, Zehui and Niyato, Dusit and Zhao, Jun and Wu, Kaishun Yang, "Artificial-intelligence-enabled intelligent 6G networks," *IEEE Network*, vol. 34, pp. 272--280, 2020.

[23] Zongyan Wang, "Digital twin technology," in *Industry 4.0-Impact on Intelligent Logistics and Manufacturing*.: IntechOpen, 2020.

[24] Concetta and Lezoche, Mario and Panetto, Herv, "Digital twin paradigm: A systematic literature review," *Computers in Industry*, vol. 130, p. 103469, 2021.

[25] Philip and Schlette, Daniel and Zupfer, Daniel and Pernul, G, "SOAR4IoT: Securing IoT Assets with Digital Twins}," in *Proceedings of the 17th International Conference on Availability, Reliability and Security*, 2022, pp. 1--10.

[26] Abhishek and Katta, Vikash and Colomo-Palacios, Ricardo Pokhrel, "Digital twin for cybersecurity incident prediction: A multivocal literature review," in *Proceedings of the IEEE/ACM 42nd International Conference on Software Engineering Workshops*, 2020, pp. 671--678.

[27] Judith and Pfeiffer, J, "Integration challenges for digital twin systems-of-systems," in *Proceedings of the 10th IEEE/ACM International Workshop on Software Engineering for Systems-of-Systems and Software Ecosystems*, 2022, pp. 9--12.

[28] Birgitta Dresp-Langley, "Seven properties of self-organization in the human brain," *Big Data and Cognitive Computing*, vol. 4, p. 10, 2020.

[29] Nathalia Moraes and de Lucena, Carlos Jos, "Fiot: An agent-based framework for self-adaptive and self-organizing applications based on the internet of things," *Information Sciences*, vol. 378, pp. 161--176, 2017.

[30] Junjie and Huang, Yan and Xie, Zhenzhen and Han, Qilong and Cai, Zhipeng Pang, "Realizing the heterogeneity: a self-organized federated learning framework for IoT," *IEEE Internet of Things Journal*, vol. 8, pp. 3088--3098, 2020.

[31] Tie and Chen, Ning and Li, Keqiu and Atiquzzaman, Mohammed and Zhao, Wenbing Qiu, "How can heterogeneous internet of things build our future: A survey," *IEEE Communications Surveys \& Tutorials*, vol. 20, pp. 2011--2027, 2018.

[32] (2022) Powering the Smart Construction - Digital Twin technology with Vi 5G. video.