AI IN DIGITAL TWIN

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Abstract-Trending **technologies like ML, AI, Deep learning, IOT, Big data have paved a way to introduce digital twins. Digital Twin connects a path between physical and digital worlds. There have been problems with manual inspections, delays in finding where the problem lies, inefficiencies, static data, historical analysis, low performance, human judgmental issues, inventory mismanagement, wrong decision making, unpredictable capabilities and many more. To solve such problems Digital Twin has come to transform these problems into solutions. By integrating AI algorithms this has become easier and more productive. In many fields such as manufacturing, healthcare, farming, networking, ITS etc. digital twins are being used.**

This paper reveals the challenges by increasing data in IOT devices affecting the data accuracy, storage, efficiency, latency for AI integrated digital twins. This Digital Twin is a visual representation of an originally placed physical object. These objects are attached with a sensor which updates data through IOT devices. These IOT devices send vast amounts of data and that becomes complex. Managing this complex data becomes a major challenge. Using edge computing will reduce latency and increase decision-making to a greater extent. Along with that, storing data in cloud with distributed data processing models would help taking high amounts of data and then sending them to their respective nodes.

With AI rapidly increasing digital twins will also increase and in the coming future it will be able to handle complex failures, it can even adjust without any human intervention. Other technologies such as 5g and beyond that, Quantum computing, edge, and fog computing, blockchain, AR & VR, Robotics etc. would integrate with digital twin in the future. These integrations result in smart and faster growth in predictions, and decision making in all the industries.

Index Terms**—Artificial Intelligence, Internet of Things, Digital Twin, Machine Learning, Neural Networks, Deep Learning, Quantum Computing, Edge Computing, Decision Making, Fog Computing, Big Data, Predictive Maintenance, Real-time monitoring, DRL, Cybersecurity, IoV.**

I. INTRODUCTION

Digital Twin technology was first used by NASA with Apollo 13 mission. Simulators were used to model the spacecraft and to know if oxygen tanks fail. This step was taken by NASA to get the crew safely on to the earth and digital twin made it happen. From then to now there have been many advancements in digital twins. With Digital Twin, continuous real time monitoring from sensors and IOT devices gives feedback on its condition. Thus, the decision makers can look at the specific condition and take decisions. AI can help with this by providing deep predictive insights and data analytics to give a solution. If there is a prediction that a machine part may fail or some problem might occur, this digital twin does maintenance check before itself so that there might not be more repair cost and downtime.

This Digital Twin Technology highlights essential information about how things work in the real world. They have some characteristics like connectivity, modularity, homogenization, digital traces, reprogrammable and smart. This works on elements like past data, present data, and future data where past means historic data, present means data which comes from sensors, IOT devices etc., Future means predicted data, data insights from ML algorithms. In various industries DTs are being used. In manufacturing, DTs are used for developing a product, performance improvements, designing and predictive maintenance of the system. In retail, DTs are used to improve customer experience to attract them in order to increase sales. In healthcare, DT's help in services which help in improving patient care, cut costs. In automotive vehicles, DTs are used to analyze and identify any problems, design etc.

In the coming years, not only humans will get the pros of digital twins but also the earth can get benefits. Digital Twinn of the earth can predict rise in temperatures in sea, land etc. It can predict the impact of deforestation, natural disasters, climatic change, and its causes. This would help governments and NGOs to make decisions. The government would be ready for natural disasters before they may occur. This would reduce costs, save many lives, and make it easy for the disaster management team. Along with that, the government would understand climate change in a better way and propose new solutions to reduce the impact of climate change. This would help nature and all living beings. Digital Twin can replicate anything which has a shape and size. This technology can do wonders and help in solving problems.

II. AI IN Digital Twin- CURRENT SECTORS

A. Healthcare

The integration of healthcare and technology will boost growth, increase efficiency, reduce costs and treatment for any health issue would be handled well. Digital Twin in healthcare can save lives in emergency situations. For instance, apple smart watch which has heart rate sensors senses the heartbeat rate and if there is a heart attack indication it would send the data and call emergency services for help. This alone saved many lives. What if there is digital twin employed in healthcare.

A human digital twin if created for a patient then all the information of the patient is recorded. But this again is complex, as we must create different human digital twins for different humans. For instance, the patient's age, gender, previous health conditions, present health conditions, medications, etc., should be recorded. This model is used to monitor the patients' condition continuously with the help of sensors like blood pressure sensors, pulse oximeters, ECG, EMG, oxygen sensors etc. Along with the sensory model's behavior models are also created. These behavior models imbibe the data such as the patient's medical habits their sleep patterns, Physical habits etc.

All these models help and monitoring, medical reminders, treatment plan management, pill reminders, emergency alerts etc. With this early disease prevention and detection, emergency warnings can take place. Lastly for the production we use data analysis techniques to analyze the data. Various algorithms of AI and ML are used to provide healthcare services, diagnosis, panic alarms etc. The data is sent to virtual space, and the necessary steps are taken to improve the performance and efficiency of digital twins.

B. Manufacturing

In the manufacturing industry, digital twins are used in designing, producing, and maintaining the products. This happens with the help of IOT sensors, All the industries get the benefits of digital twins as it creates a virtual replica of the product. The manufacturers can get performance of the machine, optimize the efficiency, reduce costs etc.

In these industries, IOT plays a crucial role with digital twins. IOT related devices used in digital twins are sensors, actuators, and connections which give data to digital twins. The role of IOT can be divided into 4 sections:

1)Collection and continuous monitoring: In this, the data is collected from sensors and the continuous monitoring happens on the actual equipment. This collected data has variables like temperature, vibration, pressure, consumption of energy, performance etc.

2)Predictive analytics: The digital twins use past data send them to the IOT sensors and thus they predict the breakdowns, maintenance scheduling, reduction of downtime.

3)Remotely monitoring: As the employment of digital twin gives the access to design, maintain, produce remotely. The manufacturers can handle everything remotely.

4)Closed-Loop Manufacturing: Feedback loop in digital twin enables fast decisions that help in improving performance, efficiency and reduce waste.

AI helps in manufacturing with digital twins by making autonomous decisions, processing optimizations, Quality control.

1)Optimization: Manufacturing workflow needs to be improved by using various processes and configurations. AI has algorithms which help in optimizing the performance, reducing the downtime

2)Autonomous decision: Autonomous means automatically making decisions without human intervention. AI gives control to digital twins to make decisions. This would reduce human power.

3)Quality Control: AI helps in analyzing the data and detecting the problems in production quickly, this helps in correcting or solving the problem there by avoiding large data untouched or not affected. This enhances the quality, and it reduces waste and rework.

C. 6G Network Communications:

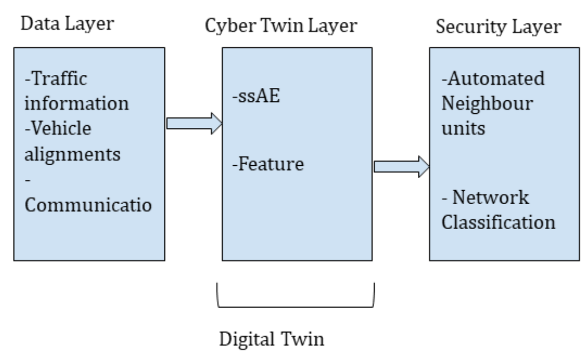
In digital twins, we come across various use cases and one such prominent use case is its implementation in 5G and 6G networks communication. As the population increases day by day along with the usage of the wireless networks, there comes the need for an intelligent management/decision-making of these networks and that is where the AI comes for the rescue which can typically handle allocation of the resources, automatically predict and fix the network issues and controls the traffic with the help of digital twins. While the digital twin concentrates on being a virtual copy of the network continuously replicating the real networks, the AI does the predicting, monitoring, detecting, and optimizing the networks by implementing the changes without human involvement and takes the decisions on the real time basis. Also, the 5G networks lack pervasive intelligence, there is a huge requirement in the 6G for comprehensive intelligence (by introducing AI everywhere i.e., every part of the networks). When integrated the 6G with the Digital Twins enabled comprehensive network intelligence with uninterrupted communication between the digital and physical systems provides more versatile, reliable, intelligent decision making, self-instructing and self-monitoring. The digital twin utilizes the AI and machine learning models to process the large amount of the data at the networks in which the edge computing plays a vital role implementing the digital twins to the nearby end user location which further helps making the decisions quickly by reducing the latency.

The key challenges by the 6G networks being the computational complexity and the latency in the communication while the digital twin faces challenges in terms of when large numbers of devices are connected, and the heterogeneous structure of the network makes it more complicated. [3] which introduced a model by integrating digital twins with the edge networks solving two problems: placement of the digital twin and migration of the digital twin through the deep reinforcement learning (DRL) and the transfer learning methodologies, respectively. As the digital twin deals with mobility issues, this paper [3] addresses adaptive edge association where the digital twins can be moved automatically to the most accurate places (edge of a network i.e., edge computing) in real time on a network with the use of DRL. Streamline the DRLs learning process and quickly transfer the information the transfer learning is employed. The Reward function is used to make the decisions for the edge association in an optimal way. The loss function, which differentiates between the predictions made by the AI and the performance of the actual network, plays a significant role in AI. The overall aim is to reduce the latency and the cost of the deployment in the 6G networks with edge adaptive association.

One aspect of the digital twins is that the digital twin gathers the network's data then with AI understands and makes the decisions. This way the network autonomously makes the decisions(self-learning) with the help of digital twins by making the decisions like detecting the issues and fixing them back and adapting to the dynamic environments. The challenges we face are the trust issues we invest in the autonomous networks which prepare us to face unexpected challenges/issues. The digital twin with the AI simulates and tests first in the digital environment and then implements the right one in the real environment efficiently implementing in a closed loop manner.

D. IoV with Cyber-resilent:

As we deep dive into the digital twins in the 6G networks (considering here the vehicular networks case), the security is an impactful parameter. In any technology, the security implementation is crucial and prevents attacks. A framework is utilized to make cyber-resilient networks in the 6G IoVs(Internet of Vehicles). The challenge with the vehicular networks is that due to the dynamic and mobility nature, there is lots of information available which becomes difficult to handle and is prone to various cyber network attacks such as the breaches or DDoS(Distributed Denial of Service).The AI with a digital twin in the introduced framework help with real time monitoring, detecting and predicting of the cyber-attacks. This framework utilizes ssAE(Stacked Sparse Auto -Encoders) technique which helps in detecting the anomalies (and patterns with irregularities) in the traffic of a network. Once the attack detection takes place, the strategies for the mitigation are implemented in real time before even deploying them. The digital twin gets the data from the real time systems (IoV) continuously and with the help of AI models such as ssAE, it can detect the pattern irregularities/anomalies which specify the cyber-attacks. Along with the identification of cyber-attacks this framework also provides low power consumption and low latency.



Figure(i) The architecture for the cyber resilient 6g IoV networks

Figure(i) depicts the architecture of the system comprising three layers: the data layer, the cyber layer and the security layer. The data layer does the data collection job from the network which is then fed to the cyber twin which represents the virtual real system. The security layer has the algorithm and the ssAE to classify and detect the anomalies, respectively.

Thus, the digital twins with AI enriched with the comprehensive network intelligence, edge association with cyber security safeguards in IoV ensures the minimized energy and latency with maximum and efficient resource management provide an ultimate security solution for the 6G networks.

E. Power Systems:

Digital Twin technology is revolutionizing the management and operation of modern power systems. Classically, power grid processing has been based on physical models and static simulations, which allow carrying out critical tasks, including load management, fault analysis and grid optimization. However, the development of new complex power system structures based on renewable sources and distributed resources requires a more expressive, data-driven approach. Digital Twin technology also becomes a new way to solve this kind of problem because it can create a real-time imitation of the physical structures like the power grid and allow the operators to run the systems more precisely.

Specifically, at its foundation, a Digital Twin is an updatable database of a physical system to which it corresponds—here, the power grid. This digital model is then updated in real-time in relation to the grid through data pulled from several sensors and IoT devices installed on the system. These devices include sensors that record voltage, current, temperature and load data among others and feed the information to the digital twin in real time. This real-time integration allows the Digital Twin to reflect the status of the physical grid and provide a highly accurate and ITTC representation of the system conditions. In contrast to other forms of simulating, meaning the ones where certain conditions are set, Digital Twins are dynamic entities, changing as they update with latest information; this makes it possible to keep an eye on how the grid performs and what can be done to the same in response to current information.

Real-time monitoring and control are among the biggest advantages of Digital Twin technology in power systems. Some of the aspects that an operator can identify from the virtual model of the grid include power discrepancies, equipment faults or threats such as a cyber-security vulnerability before they become critical events. For example, an excessive temperature in a transformer is detected by the digital twin, and operators subsequently prevent further deterioration leading to equipment failure or disruption in power supply. Due to the visibility which comes with the use of Digital Twins, management of the grid can be done proactively, which is important given today's much more complicated power systems, than before.

Another benefit of using Digital Twins involves identifying impending system faults and preventing them by calling for deserved maintenance. Through constant data acquisition of the grid, the digital twin would be able to determine deterioration or failure in system components before they autonomously reach a critical level. For example, small deviation in the output of a power line or a generator showed that the component needs maintenance, while the Digital Twin estimates the time until the component failure. The predictive functionality can help identify when maintenance will be required and can therefore prevent equipment downtime and expensive sudden repair costs. In this manner, the Digital Twins help to enhance the availability and dependability of power systems while providing opportunities for early problem identification.

Digital Twins also has a significant function in the enhancement of grid functionality, especially in incorporating renewable energy systems. With incorporation of solar and wind power into the grid as sources of energy, the fluctuality of the production is a complicated factor. Digital Twins can operate the renewable energy data streaming together with the demand, storage, and distribution side of the grid. They can suggest changes that should occur to the energy distribution system, manage supply and demand appropriately, and make certain that renewable energy sources are being effectively used. Some of them can even self-optimize certain functions of the grid and make near real-time decisions for optimizing the operation based on conditions that have been known to cause instabilities.

Altogether, Digital Twin technology can be considered as a high potential tool for the contemporary adjustment of power system processes. Thus, the availability of real time monitoring, automated inspection and control ensures that power grids become more robust, performing, and ready to face demands of growing complication and renewables integration.

F. Education

In the past, class management and assessment of students' performance often included paper and pen-based practices with limited technological integration. These techniques have been helpful in tracking such things as attendance and academic performance, but they are not adequate in offering a continuously updated picture of student deportment and class performance. This is especially true in current and ever more complex learning contexts where various variables may affect learner achievement. Hence, Digital Twin has been presented as an innovative approach providing real-time and forecasts for educational systems, like the case of using the technology in industrial applications, such as power network.

Digital Twin Education is hence referential to a mirror and real-time actualization of an existing physical entity, for instance, a class or individual learner. This digital counterpart holds the current state of the educational environment against data feeds from sources such as LMS, attendance and interactions with resources. This is because software, reports and IoT devices offer real-time information of academic progress, participation, and engagement of students. As the Digital Twins are constantly updated and necessarily reflect student requirements and class activities, educators can control and adjust their actions far more accurately than is possible with traditional approaches, like power grid operators and the work with load management and faults.

First, constant control of student performance is one of the main advantages of adopting Digital Twin technology during education. Such problems can include erosion in performance, truancy, or changes in behavior – and these can be identified early enough before they become total crises. For instance, if the student has a mediocre performance that sudden drops and the Digital Twin can signal the instructor and advise the student to avoid potential failure.

The second benefit may be attributed to the predictive capability of Digital Twins, especially in determining students' performance and identifying failure. Through continuous evaluation of the data fed into the Digital Twin, the solution can foresee when a student is likely to struggle or perform poorly at school. For example, slight deviations in how the student is engaging with learning content might signal the student is no longer interesting, and the learning system should intercede early. Likewise, power grid Digital Twins employs data from sensors to calculate the equipment wear and schedule the maintenance ahead of time so that the equipment would run at its best without a chance for a failure.

Also, a Digital Twin has a critical role in the improvement of the general functionality of educational systems especially in the aspects of adding adaptability to learning environments. Due to increased learner differences, it causes variations in performance based on factors such as learning preferences as well as other environmental differences makes the management of learning more challenging. Digital Twins can aggregate information on these variables and suggest differential adjustments to the curricula or to the instructional approaches. Consequently, Digital Twin technology can be mentioned as a high-potential modernizing solution for contemporary educational monitoring systems. Thus, Digital Twins, being data-driven and predictive prescriptive tools put educators into the position to actively monitor and manage student outcomes and class dynamics in real-time.

G. Transportation

In transportation regions there are some problems arising in society for numerous reasons. The list consists of traffic management, smart mobility, health management in transportation. The objective of digital twin for smart traffic management is to develop a real time, self-organizing traffic system to address the enormous requirements of transportation in the congestion dense cities. To address the issue there is a trending technology called Digital Twin integrating with AI called an AI-based Digital Twin Framework. This is done using real time data fed into the DT's using AI and other intelligent algorithms to provide a real time model of traffic environments in premier Indian capitals.

The proposed framework has three components including the following:

Integration of data in real time: The DT's takes inputs from traffic cameras, GPS assisted cams, weather radars, and administration database. This info is extremely useful for generating a real-time replica of traffic situations in cities like Mumbai, Delhi, or Bengaluru which struggle with numerous traffic problems. In terms of digital information, the system constantly keeps a complete model of the transport network of cities.

Flexible type AI Architecture: The architecture of digital twin is composed of AI modules and where each module focuses on a specific function. This design can scale, and it is easier to add or subtract services on the page. For example, some of the AI sub-sections can be applied to preliminary vehicle inspection, studying the road surface, and identifying incidents. Due to this condition, it becomes simple to make alterations or swap out specific portions of the system, thus holding high efficiency of the DT'S as it acts to new consequences and innovations. Here DIP is performed by using ai models called deep learning models. For example, the device may use You Only Look Once to detect objects such as vehicles and walkers from feeds from cameras. New machine learning models applied this approach to study traffic conditions with the view to determining future conditions, hence a faster approach to intense traffic in the urban areas.

Decision-Making and Predictive Analytics: One of the essential competencies of the system is the ability to estimate traffic flow based on past and current data. The framework uses deep learning models, including CNNs, on historical traffic data and makes predictions on the future traffic data. This way authorities can change control measures which seek to address traffic concerns before they become a problem. Using image recognition and anomaly detection, the digital twin can identify accidents, obstacles, and many other deviations from the normal way. This can quicken the authority's actions such as a change of traffic direction or an action in relation to an incident.

Benefits of the framework listed below:

Proactive Traffic Management: The digital twin can use real-time data to make real-time changes to traffic signals and routes for vehicles and even regulate traffic flow. This proactive operation mode relieves congestion and improves efficiency in general motor vehicle traffic, especially in high-density areas. The capability to use weather data means that the system can detect and even overcome problems which may be caused by severe weather. For example, during squalls the system can boost the signal timing to counterbalance slower speeds on the road and reduce crashes.

Enriched Safety: Some of such advantages include fast identification of cases such as an accident or any dangerous situation, then prompt notification to authorities. This capability cuts response time and helps to manage traffic during incidences of emergency.

Scalability and Flexibility: The system can be easily updated or expanded as the organization's needs are bound to change with time. Whenever there will be a new sensor or a new source of data the universal system does not have to be redesigned and thus the digital twin remains a scalable solution for different

Indian cities which are going to face new challenges in terms of managing traffic.

Constant Learning has provided for adaptation based on new data that keeps on being input in the system hence suppleness. As more data is gathered the AI models become more accurate in estimating and hence traffic management is enhanced.

H. Farming:

Agriculture is amongst the highest sections that suffer the most from inefficiency in terms of real-time crop monitoring and management. Most of the conventional farming practices are heavily dependent upon manual observation, which is usually inaccurate or untimely. This results in inconsistent yields with poor resource utilization and heightened operational costs. These concerns are taken in only gone the destruction has been done, such as adjustments in weather, deprivation of soil, and pest infestations, triggering considerable economic losses and lower quality of crops. Further, farmers are increasingly facing pressure for productivity with environmental sustainability-a delicate balance to strike unless aided by superior technology. In this context, such inefficiencies involve a drag on farm optimization and full output.

All these issues in modern farming and many more are answered by Digital twin technology, abetted by AI. A digital twin is a virtual but real-time representation of the physical farm created from data captured by IoT sensors and devices. Using this system, any farmer operating anywhere in the world can monitor the activities happening on his farm regarding the growth of his crops, the soil's health, and the prevailing environmental conditions. All the information is processed by AI algorithms in the DT's, analyze farming acts, and estimate the impending pictures. Therefore, informed decisions are possible from farmers using up-to-the-minute data. For the first time, farmers have full control over farming activities: crop growth and resource usage are optimized while enabling farmers to take immediate measures against environmental changes well before the development of critical situations.

Proposed Framework and Components:

The underlisted are the components that constitute the AI-based Digital Twin framework intended for farming. This framework is going to provide end-to-end solutions to monitor, to make decisions and to supervise supplies in a real-time manner.

Real-Time Data Integration: The digital twin system acquires information from a group of IoT sensors installed in the farm such as temperature beams, humidity finders, soil humidity, and weather estimating devices. This real time assimilation of data should ideally put out a screen that would portray a real view of the physical state of the farm. The DT's can then make numerous ecological changes and find specifications which could be perfectly suitable for the crops.

Analytics and Imitation: AI models analyse the above data to discover the underlying trends, forecast the future of farming, as well as 'play out' various data-based farming situations. Application of AI in such a system empowers it to estimate crop growth, potential pest infestations, and what changes in the weather will do to the crops. This will help one to make preventive decisions. AI can also replicate farming operation such as irrigation, and distribution of nutrients, and other farming important processes in a bid to optimize usage of inputs and yields.

Automation and Predictive Decision Making: This can make it possible for DTs to suggest certain actions in automation like irrigation regime, fertilizer usage, or pest aggressive invasion control among others in line with present environment. Automation reduces human interference significantly; the implication is that productivity is accomplished, and the probability of error is reduced significantly. And since risks include things like extra weather occurrences or unexpected outbreaks of pests, then through predictive decision-making farmers will be prepared in advance.

Defense and Data Safeguard: AI plays a key role to provide security to the digital twin system so it can perform the following tasks: It constantly analyses the data looking for any irregularities or discrepancies and for example can show equipment breakdown, systems' malfunction, and sometimes even cyber threats. As for those, replies might be initiated to ensure the stability of the system and guarantee that operations on the farms proceed correctly. This additional layer of security through AI is the major factor needed to ensure operations cannot be breached and sensitive farming data gets shared as more farming turns into a data-driven smart, intelligent operation using technology.

Benefits of the Proposed Framework:

Proactive Farm Management: The digital twin thus provides the facility for real-time and remote monitoring of farm activities. Thus, the farmers can attend to many issues that may occur in the future very effectively, for instance the early detection of disease affecting crops, or variation of water level during sever weather conditions. This approach means that there is less loss on the farm and that efficiency increases.

Improved Resource Application: The digital twin would monitor continuously the use of water, energy, and fertilizer so that resources are utilized efficiently. This framework assures less wastage, which means cost reduction and environmentally sustainable farming through automation in irrigation and fertilization.

Expanded Productivity and Yield: In addition, AI will be applied to predict the best crop growth patterns. This digital twin framework makes it easier to provide farmers and other livestock keepers with first-hand information they can use in making decisions, and since this data can be animated and modelled in the real time, it could lead to even higher yields and better-quality products.

In conclusion, Al-driven Digital Twin technology holds promise to transform several industries by optimizing system behavior, refining decisions made, and providing an inherent feature of predictability. Digital Twins will act as a real-time data analysis tool, in increasing Al capabilities for optimization and automation as Al continues to progress at Al Technologies, these require fusion that can lead to more intelligent systems that adapt to changes in different conditions to drive more efficiency and innovations.

In special interest, these innovations are in healthcare, manufacturing, education and power systems, farm industry, transport and 5G/6G networks and so on. In each of these fields, Al- enhanced Digital Twins can simulate and monitor the overall process and predict the outcome to manage the resources and operations effectively. But issues such as data protection, security issues and infrastructure incapability of handling bigger loads are some of the main hurdles that need to be met to unlock the full potential of Al in the use of Digital Twin in various sectors.

III. AUTHOR CONTRIBUTIONS

Rishika Kandrigal: Worked on the ideas and formulated the sections on Healthcare and Manufacturing and reviewing of the document.

Venkata Sai Ganesh Kandula: Focused on research, gathering of the information and formulated the sections on Farming and Transportation.

Tejasri Kari: Researched on the digital twin, contributed to drafting the sections on 6G Network Communications and IoV with Cyber-Resilience and has done the document proofreading.

Satya Sowmika Kappala: Authored the first drafts on Power Systems and Education, worked on the illustrations and reviewed the documentation.

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