Digital Twin in Intelligent Transportation Systems: a Review*

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***Abstract*— This study reviews the research works published in the last five years on Digital Twin (DT) technology for intelligent transportation systems, focusing on the use of DT in electromobility and autonomous vehicles. The review is carried out systematically, considering specific domains within intelligent transportation in which DT technology is applied in combination with Internet of Thing and 5G technologies. In addition, the paper discusses the current issues in electric vehicle services, such as tracking, monitoring, battery management systems, and connectivity, and how they can be addressed effectively through DT approaches.**

***Keywords:* Digital twin, Electromobility, Bigdata, 5G, IoT, Autonomous Vehicles.**

I. INTRODUCTION

Conventional vehicles using an internal combustion engine consume fossil fuels and emit gases such as carbon oxides and hydrocarbons, which is one ofthe reasons for the environmental crisis. Electric vehicles (EVs) have been introduced, developed, and improved over the past few years to overcome this issue [1]. However, the distribution of charging points, the volume of EVs, and all dynamic operations in the EVs network should be managed effectively and safely. For this goal, a simulation platform was introduced to simulate the EV's network components and the interaction. Most simulation platforms support the concept of Digital Twin (DT), which provides an excellent capability to simulate the real-world entity in the industrial environment. DT concept is known as a virtual replica of a real-world object that can give the ability to study the development of physical objects in a digital situation/environment. DT was considered one of the world's ten strategic latest innovations for 2019, with autonomous vehicles (e.g., self-driving cars), immersive technologies (virtual reality and augmented reality), and quantum computing [2]. The main idea of this technology is to replicate the physical object behaviour in a virtual environment that can produce the same output as the real physical object.In particular, DTs are used in a wide range of applications, including transportation, manufacturing, medicine, business, education, and more.

In this paper, we review the research works published in the last five years on DT technology for transportation systems, focusing on the use of DT in electric mobility. The provided review is carried out systematically, considering specific domains within Intelligent Transportation Systems.

(ITS) and Autonomous Vehicles (AV), in which DT technology is applied in combination with the Internet of Things (IoT) and 5G technologies. In addition, the paper discusses the current issues in EVs services, such as tracking, monitoring, Battery Management Systems (BMS), and connectivity, and how they can be addressed effectively through DT.

The remaining part of the paper is organized as follows. Section II presents DT application in intelligent transportation systems. Moreover, Section III presents the key technologies used in combination with DT for enhancing its application to electromobility. Section IV summarizes the electromobility challenges and possible DT solutions and Section V draws the conclusions.

II. DIGITAL TWIN IN INTELLIGENT TRANSPORTATION SYSTEMS

With the advancement of Big Data (BD), IoT, Artificial Intelligence (AI), geographic information, and global positioning, a new generation of information technology is being developed. The linkage of all these technologies in the DT technology is a critical element of the digital wave trends and takes the lead in transportation applications in planning, maintenance, security, and other aspects. Many applications have been involved in research activities to give rise to smart electromobility. The rapid growth of smart control systems led to several developments in the ITS industry. The data generated through this growth is the key factor in improving the electromobility sector. The strength of the DT lies in collecting these data, visualizing it, and conducting statistics in which advanced analysis tools are used to improve the sector and help in decision-making.

The DT has the potential to improve the transportation sector by providing a digital identity, synchronized visualization, virtual and real interaction. The DT technology utilizes intelligent technical advantages such as controlling traffic perception, road warning, and emergency response. Furthermore, it can provide

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They used vehicle-to-cloud communication to calculate the advisory speed based on the information that could be collected from the sensors on the vehicles. The proposed model helps the driver to control the speed intelligently. Another example for using DT in the clouds is proposed by Alam and Saddik [4]: they developed a DT model for the cloud-based Cyber-physical system (C2PS). They described the key properties of the C2PS and introduced a telematics-based prototype driving assistance application for the vehicular domain of C2PS, vehicular CPS.

In this context, a review paper in DT technology with smart EVs has been done by Bhatti et al. [5]. The review has been divided into different categories within the smart vehicle system: autonomous navigation control, advanced driver assistance systems, vehicle power electronics, vehicle health monitoring, BMS, and electric power drive systems. As a result of this research, smart EVs and DT technology are investigated theoretically to see what impact their integration can have in the future.

Due to the amount of data generated by transportation systems, Machine Learning (ML) and Deep Learning (DL) techniques are employed to create ITS. The application of intelligence in the transportation field is rapidly increasing. DT can control, analyse, and operate the existing transportation system. Using ML and DL in DT can collect real-time data and provide very effective services to the service provider and the end-user [6]. Moreover, the ITS can effectively optimize and coordinate traffic conditions based on DL and DT technologies by monitoring the flow of people, traffic, and roads. It can also optimize the duration of traffic lights and find the signal light scheme with the shortest transit time. For example, Zhihan et al. [7] proposed a DL algorithm to solve the security problems of the ITS. The proposed model assured a response time to emergency alerts and increased the prediction accuracy. Moreover, vehicles will travel more quickly because they can better adapt to the road environment, transmit data faster, and develop routes that take into account traffic patterns. Another example of how DT and AI technologies are utilized in the transportation sector is traffic management, prediction, and congestion avoidance. Kumar et al. [8] introduced an ITS that uses ML, fog/edge analytics, data lakes, DT, and blockchain. The authors used cameras to collect environment information and then run edge analytics on the collected data. The DT was used to generate the virtual car model to simulate the real-world scenario. ML and DL algorithms have been used to predict drivers' intentions in this work. By creating a virtual vehicle model, non-autonomous drivers were able to make better decisions depending on the current traffic scenario and the intents of other drivers.

Traveller's driving experience is also an important aspect where the DT can be employed to reduce and redistribute waiting time at intersections. Sagar Dasgupta et al. [9] worked on a DT approach for adaptive traffic signal control to improve user driving experience. They developed DTs to emulate vehicles close to the intersection and vehicles' waiting time at the immediate upstream intersection. The proposed model can balance waiting time across a signalized network to improve the travel driving experience in congested areas, and it can be scalable on the city-wide network. While the Data analytics in the DT concept is still developing, Aslanietal. The authors in [10] developed a DT simulation model that can provide a performance measure in real-time. The study also demonstrated the data scarcity required for real-time applications that rely on high real-time frequency connected corridor data streams.

In summary, the DT uses all the gathered data and accurately captured city signs to achieve new insights into urban traffic on different sides, such as the road supply and traffic demand, optimising the road network structure through traffic simulation, and improving overall traffic efficiency in the city. In addition, using DT in intelligent transportation can improve the decision-making execution, safety, stability of vehicle driving and accelerate intelligent and safe driving.

For charging, an EV is commonly vital to physically attach/connect a swift charger at a household or in a public place to a car through a charging cable. Considering that EVs and self-driving accomplished by automated driving will derive into general use, physical charging is not manageable, and automatic charging should come in place. Generally, there are two options to charge automatically: park a vehicle inanaccurate position so that the charging connecter of the vehicle automatically fits the charging cable of an available charger or wireless charging. Shikata et al. [11] introduced a vehicle simulation technique using a DT, focusing on two factors, 1) power consumption and 2) ride comfort. The simulated environment contains a vehicle model for interpreting the physical performance of the vehicle. An electronic control unit has also been simulated as a prototypical for regulating the simulating environment. They also developed an automatic charging system for EVs to charge the vehicle automatically after parking in an accurate position.

BMS in electromobility is also essential concerning battery life, safety, and reliability. It relies on different types of sensors, actuators on the EV that provide real-time battery performance, SoH, and SoC to the user and operators. Using an IoT platform to build a DT for BMS in the cloud boosts the robustness of the BMS. Wang et al. [12] reviewed the solutions for BMS issues based on DT, such as the problems related to real-time estimation, dynamic charging control, and dynamic equalization control in a smart BMS.

Another critical application on the electromobility systems is the ADAS built to enhance driver experience and the safety of passengers and pedestrians by decreasing vehicle accidents and alerting drivers of possible dangers. Liu et al. [13] introduced a new vision-cloud data fusion approach to enhance the performance of visual guidance systems by leveraging DT technology and cloud servers. This work is one of the adequate studies to visualize the cloud DT data and support the ADAS or driver's decision making.

III. TECHNOLOGIES ENHANCING DT APPLICATION FOR ELECTRO MOBILITY

A. *Internet of Things*

Recently, IoT technology has been used in the context of intelligent electromobility. In the electromobility revolution, the application of DT technology is facilitated through advanced data analytics and IoT. Digital and physical interaction are changed by integrating DT and IoT platforms. IoT enables connection and intelligence access of physical devices, and the DT can handle challenges of integration between the IoT and Data Analytics, which facilitate making rapid real-time decisions. In electromobility, IoT establishes a broad platform with connected vehicles that can send the data from physical devices to the cloud or local servers. Then the role of the DT lies in dealing with this information, simulation of resources by creating DT models, establishing virtual connections, and integrating with artificial intelligence. Therefore, the DT technology is a powerful technology to improve performance innovatively in electromobility and gives advances in monitoring, analytical and predictive capabilities [14].

Zhao et al. [15] introduced an IoT and DT model that enabled tracking solutions for safety management. The proposed framework allows a safety tracking mechanism for detecting stationary behaviour and self-learning genetic position to recognise the abnormal condition and obtain an accurate location in real-time.

B. Virtual Sensors

Electric vehicles use many sensors in their environment to perceive and act according to what they perceive. This scenario illustrates the likelihood of generating a logical entity in place of a physical sensor called Virtual Sensors (VSs). VSs can provide services for intelligent transportation and solve many issues related to the battery charge and enhance root planning for EV drivers based on parameters estimation/prediction. In particular, a VS derives new data from existing information generated by the physical sensors and utilizes a data processing algorithm to process the input and produce the required output [16]. For example, Roccotelli et al. [17] introduced and designed new virtual sensors to enhance the EV charging experience. The proposed model provides a smart charging service that allows the drivers to find the best charging point for their vehicle. Another example, Gruosso et al. [18], proposed a methodology for estimating the state of charge (SoC) in EVs. The method relies on the VS and other measurements available in the vehicle, such as speed, acceleration pedal position, and battery voltage. VSs also play an essential role in enhancing user experience and optimizing EV services, which could support the growth of the EVs market. In [19], Fanti et al. developed a new EV service to improve user experience preparing for the trip. They designed three VSs that help the driver predict the cost and required energy for the journey. The proposed VSs can estimate the demand energy based on the historical data which aggregate from the past trips. Some relationships between the sensors can be determined over time by the virtualization platform, for example utilizing ML techniques and exploiting to improve the functioning of the sensors. Therefore, combining the technology of VSs with the EVs simulation model can provide a way to solve complicated issues such as battery management, vehicle energy management, and vehicle control.

C. Internet of Vehicles

EVs have the following advantages, fuel efficiency and greenhouse gas reduction; they have attracted a progressively greater share in the private automobile market [20]. With the present battery technology, the charging problem is still a barrier to the growth of the EV business. Thus, it is essential to make and organize a wide-area charging organization that holds fast charging poles, battery swapping stations, and individual charging points for faster EV battery charging. In this scenario, the EV model is simulated with the DT to accurately replicate the EV in the real world. By introducing a DT model, it is easy to simulate mobility behaviours and interactions to study the efficiency of the charging pole and EVs from the demand-side and supply-side. This simulation platform can help optimizing the charging scheduling and navigation algorithm [21].

The advancement in this area can solve the problem of managing and exploiting real-time traffic data. The vast traffic data could help constitute a DT that creates a virtual representation for the physical vehicles via various communication means.

D. 5G networks

The 5G network supports a wide range of applications in different industries. The enhancement in 5G network communication impacts industrial 4.0. Such industries are smart cities, military applications, health care systems, and intelligent transportation using IoT. The 5G network makes rapid changes in wireless communications and improves performance by increasing capacity, improving reliability, lowering latency, and increasing network speed [22]. The previous cellular technologies depend on fixed infrastructure while coming to 5G network significantly enhance the use of small cells and mobile cell sites to increase network access in congested areas. The 5G network has various applications and dynamically changes latency, bandwidth, and reliability requirements. These requirements have a high impact on the deployment of the 5G network in EVs.

5G is largely used in EVs for communication between the EV components. The Rapid transformation and fusion between industry and communications systems have made significant renovations on the highways, especially in self-driving. This development affected many applications, such as the roll-out of 5G networks, the Internet of Vehicles (IoV), and the adoption of Cellular Vehicle-to-Everything (C-V2X) connectivity. As a result, when the 5G is connected, vehicles exchange traffic data, highways, traffic signals information, roundabouts without human interference [23].

The 5G network-connected vehicles will generate massive data and have more autonomous functions. Smart cities depend on effective management, and connected devices generate huge data. The 5G network with DT addresses the smart city network variables. Such as capacity, reliability, mobility, latency, security. Recently, a prediction method for 5G-enabled IoV in real-time traffic using DT concept was introduced in [24]. Hu et al. worked in IoV solutions and introduced a DT-assisted real-time traffic data prediction model using 5G communication. As a result of this work, the proposed model proved to optimize the scheduling of traffic resources and mitigate possible traffic jams at peak times. By analyzing the traffic flow and velocity data measured by IoV sensors and transmitted over 5G communications, the authors believe the proposed method can be more accurate. Deng et al. [25] proposed a combined approach of DT, reinforcement learning, and expert knowledge for the self-optimization of current networks performance 5G, and they described potential application scenarios for 6G.

To solve the problem of end-to-end delay and reduce the processing time at the local servers in many emerging critical applications. However, Dong et al.[26] adopted a DT framework of the current network. The proposed framework based on DL algorithm achieved lower energy consumption with minimal computing complexity.

E. *Artificial Intelligence for Autonomous Vehicles*

The recent research in electric vehiclesfocuses on AVs, also known as self-driving or driverless cars, i.e., vehicles driven without human intervention. Such vehicles are electric vehicles since electric propulsion is easier to govern autonomously. With the advanced technology, the vehicle will sense the surrounding environment, route plan, and drive thanks to AI and ML technology [27] safely. The AV is still under testing and has not yet become popular globally, but in the coming years and due to its great benefits, the AV will occupy the global market and vehicles industry. Although AV has been an active research and development area in the last decades but still faces a lot of challenges to develop a fully automated vehicle system. Consideringroad conditions, traffic conditions, weather conditions, and communication expansion have helped the autonomous vehicle systems grow. In the following part, some exciting research that has been done on AV development is addressed.

Car navigation systems assist in controlling and making decisions based on the prior knowledge (sensors or road map) that feeds into the system. Lopes et al. [28] proposed an efficient approach for vehicle navigation systems based on the velocity optimization paradigm. The maximum speed is adjusted to the curve of the road, and the car follows a smooth path to the lane's centre. The approach was integrated into a car navigation architecture and evaluated in two separate simulators before being put to the test in an autonomous vehicle prototype.

The local route and road geometry are required for AV; therefore, Jo et al. [29] proposed a hybrid local route generation method. According to the history of performance and the map availability, the algorithm can precisely choose the best route between the available options. The proposed method was validated and verified in real traffic conditions in an urban area in Korea. In fact, verification and validation are significant challenges in AV for safety assessment. The authors in [30] introduced a systematic review to investigate AV's current verification and validation software. They discussed the simulation environments and more specific approaches such as mutation testing, fault injection, techniques for cyber-physical systems, adversarial examples and corner cases, and formal methods.

To enhance autonomous driving performance, Yang et al. [31] developed a framework that integrated the Intelligent driving model with human factors such as driving mode and their reactions and expectations in the road. The proposed model helps to reinforce the efficiency and safety in AV.

Reinforcement Learning (RL) is a widely used ML technique to train the agent on rewarding and punishment approaches. This approach effectively works with the AV industry as the RL algorithm learns from the driver's actions to increase a certain reward or take a decision. Masmoudi et al. [32] designed a framework for car-following based on video frames processing using RL algorithms. The framework is based on navigation decisions and automated object detection. The proposed model achieved promising results and acceptable car-following behaviour in AVs. Employing RL in the AV industry is innovative will benefit the AV industry. The more information algorithm processes, the more efficient the algorithm becomes, and the best results could be obtained. Software providers that support the DT have begun integrating reinforcement learning into newapplications. For example, recently, Flexsim software [33] introduced the RL model and the possibility to connect with the Flexsim models. Such additions will make the software a 3D design tool and be a data analysis tool, which enhances the concept of the DT.Rassolkin et al. [34] specify tasksrequired for a specialized unsupervised prognosis and controlplatform for energy system performance estimation for AV. They develop several test platforms, digitaltwins and machine learning algorithms to optimise electric propulsion drive systems of self-driving electric vehicles by using autonomously and monitoring sensors. In addition, Venkatesan et al. [35] propose a pre-estimation of the service requirement ofEV motors for AV using intelligent DT that employ Artificial Neural Networks and fuzzy logic in MATLAB/Simulink formonitoring and prognosis of permanent magnet synchronous motordistance.

F. *Digital Twin Network*

Digital Twin networks (DTN) are the natural evolution of the development of DT technologies in the modern era. DT of any physical object is the first cell of the DTN; thus, we can define DTN as a set of virtual digital representations of different groups of physical objects connected by a high-speed communication medium that can configure a virtual integrated system. The data exchange between the virtual model and physical object in the DT is a unidirectional way, one-to-one. The operational changes in the physical object will directly affect the virtual model but not the opposite. On the other hand, DTN allows comprehensive data exchange between DTs and physical assets in a multidirectional manner [36]. Recently, transportation has encountered issues that increase with the development of urban cities, such as traffic congestion and accidents. The different components of smart cities need to be controlled intelligently using the generated data from the physical assets. In this context, DTN can provide a better solution for such a complex environment and help to optimize the entire intelligent transportation system. DTN also offers innovative transportation services such as traffic information reporting, vehicle security, and data sharing.

To keep pace with the rapid progress in the electric mobility sector, we need to use and integrate DTN technology with EVs networks in smart cities, whether autonomous or non-autonomous vehicles, which will provide high possibilities for managing and improving transportation network systems, not only at the city level but at a broader level.

We consider a DTN architecture based on three layers: Physical layer, Network layer, and Virtual layer. The physical layer consists of EVs, charging stations, and roads and their facilities. Through sensor technology, the entities are connected to the network layer. In the network layer, the communication services are provided, either 5G, 6G, or WIFI, to establish the communication between all layers. A set of DTs and servers are located in the virtual layer to execute the simulation and computation tasks and provide communication services to the end-user.

The heterogeneous resources in the IoT networks made the efficiency are very challenging. However, it can be exploited to reduce energy consumption and enhance data processing efficiency. In this context, DTN utilizes DT technology to simulate the physical network on IoT. Dai et al. [37] proposed a new paradigm new DTN model to build network topology integrated with the IoT network. The adopted system significantly solved many problems, such as the computation offloading as well as a resource allocation problem.

IV. EV CHALLENGES AND DIGITAL TWIN SOLUTIONS

DT concept involves feeding data from the real world back into the virtual environment to improve model accuracy. This reduces the gap between the real and virtual worlds, allowing for simulation. As a result of this survey paper, we will present the important challenges in EV networks where DT can provide solutions for EV networks.

A. *Cost-Effective and Reliability*

The implementation of the EV networks is one of the most relevant challenges due to the shortage of infrastructure and safety measurements [38]. Providing infrastructure services to implement EV networks is very cost-effective. The maintenance of EVs services is also cost-effective. The model built with the DT concept can be evaluated before being deployed, thus lowering maintenance costs, making DT a cost-effective option.

The present state of the EV system doesn't have reliability in data transmission. Reliability is the main challenge in EV transportation systems to operate EVs safely under various conditions. In the future, EV transportation systems should maintain data reliability and scalability. Data attacks are significantly mitigated with DT technology, which provides greater security for the mechanism against attacks. It protects the privacy of the EV user as well.

B. *Visualization*

The data visualization gives complete scope for EV consumers to plan long-distance transportation. But the present EV system has visualization limitations. These limitations lead to the problem of testing EV functions and efficiency. To solve this issue, DT integrates 3D graphics and audio with real-world objects using IoT and AI applications. Using such technology, the operator can monitor and control the EVs and allow them to communicate and interact with DT data to improve efficiency during and after the design process.

C. Charging Time

Whether the charging system is for standard, fast, or quick charging, the charging time is still quite long. This is one of the main reasons holding back the growth of the EVs industry. There is also the need to do research in wireless charging. The DT simulation could be used to improve the charging time by analyzing the data from the model, and the result can be used to evaluate charging infrastructures and charging efficiency.

Table I: Papers classification based on the technologies and services applied to DT.

Services **Technology**	BMS and charging	User experience	Tracking, Monitoring and control	Review papers
5G	[23]	[22] [23]	[24] [15] [25]	[5] Digital twin technology [6] AI, ML, and Big Data in Digital Twinning [14] Enabling technologies, challenges and open research [30] A Systematic Literature Review [36] Survey on Digital Twin Networks
AI & ML	[11] [26]	[7] [8] [9]	[7] [25]	
IoT and cloud	[12] [20] [21]	[10] [11] [13]	[3] [4] [37]	
VS and IoV	[16] [18]	[17] [19]	[24]	
AV		[31]	[28] [29] [32] [34] [35]	

D. Review Summary

The study shows that the use of the DT concept is still in its infancy, and there is a massive benefit of the DT applications in ITS. In particular, the electromobility applications are promising and utilizing the DT concept could enhance the EV infrastructure and user experience. In Table 1, the study shows that there has been interesting work in DT from different perspectives and applications. The table classifies the paper contributions based ontechnologies and services that utilized the DT concept in the literature review.

V. CONCLUSION

This paper aims to provide a survey of the published papers in DT technology in the last five years. The awareness of DT has recently been growing exponentially due to the number of applications that demonstrate their capabilities for connecting the physical and digital worlds. EVs are an area where DT can be used to create a more effective solution, attracting bothacademics and industry. The survey answers four questions: What is DT? What are the current issues on EVs systems that need to be studied? What is the significance of DT for ITS? Finally, we discuss several major issues and major challenges that continue to influence this field of research and DT solutions, such as Cost-Effective, Reliability, Visualization and Charging Time. As future research, the security issues in electromobility will be addressed, particularly focusing on autonomous vehicles security and protect the vehicular ad hoc network (VANET) from potential attacks.

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