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RESEARCH ARTICLE

AN ANALYSIS OF THE APPLICATION OF DIGITAL TWIN TECHNOLOGY FOR THE OPTIMIZATION OF AUTOMOTIVE PROCESSES

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ABSTRACT

A computational resource, such as a computer, server, or other piece of hardware, or a software-based resource, such as an operating system, can be created in a virtual form through virtualization. A method known as "digital twins," which compares digital objects with physical ones, was developed by researchers from the aerospace administration and was first proposed many years ago. The physics-controlled system may be edited, simulated, and examined using the digital models, which are based on digital twins. Due to the quickly shifting client demands, car manufacturers are currently dealing with a number of difficulties in meeting the delivery date. This happens as a result of several kinds of car bodywork being manufactured on the same line to satisfy the demands of various models' short life cycles. Accordingly, many facilities are needed for each step since different kinds of vehicle body manufacturers must be carried out. Due to the substantial quantity of machinery required, the manufacturing facility has a convoluted production chain. As a result, there are malfunctions at various facilities, which leads to faulty goods. The aforementioned issues make it impossible to follow the manufacturing schedule. In vehicle manufacturing facilities, it can be difficult to meet delivery deadlines since unplanned anomalous occurrences, such as product faults and equipment failures, regularly happen. Private information that has unanticipated, undesirable impacts on the subject's (driver's) privacy may be included in the data acquired. The scenario's goal is to demonstrate how the Digital Twin can be used as a tool to enhance privacy that links dynamic privacy data to the services of various stakeholders, produces fresh insights into privacy parameters, and spots privacy anomalies that can then be automatically reported back to the subjects. This review paper addresses the use of digital twin technology for the betterment of Automotive technology such as production lines, privacy use and Electric Vehicles.

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INTRODUCTION

A generic phrase for providing an abstract view of system resources is virtualization. For instance, virtual memory enables each process to feign exclusive access to the whole memory address space of the processor. Of course, in fact, different parts of the computer's memory are being used by various programmes, with certain parts being relocated to the disc if there isn't enough memory for everyone. The memory management unit (MMU) of a CPU creates physical addresses that correspond to actual memory locations, giving the impression that all of the memory is accessible. Software (a pseudo-machine) that decodes the commands of a processor is known as a virtual machine. The Java Virtual Machine (JVM) is the most well-liked of these methods. Java programmes are translated into bytecodes and run in the JRE (Java Runtime Environment), which is a virtual machine that doesn't actually exist.

Most recently, we saw Android's explosive growth in popularity across smartphone and tablet devices. The majority of the software developed for this platform is compiled for the Java Virtual Machine-like Dalvik virtual machine. The idea of digital twins was put out many years ago, and it is a technology that was created by researchers from the aerospace administration that compares digital items withactual ones. The digital models, which are based on digital twins, may be used to edit, simulate, and examine the underlying physics-controlled system. A digital twins network platform may be created by integrating the technology of digital twins into the network and producing a virtual representation of the physical network facilities. The digital twins network platform enables the physical network and twin network to interact and affect each other in real-time, enabling low-cost experimentation, wise decision-making, and high-efficiency innovation. Digital twins are being employed extensively in business, manufacturing, and other sectors.

Digital twins are based on the real-time operation process of physical entities and production systems to increase the accuracy of data analysis and configuration. They are a virtual embodiment of the design, building, and maintenance of actual entities. IoT and digital twins technology development has increased due to falling technological prices. The most typical instance of virtualization is when a hard drive is partitioned during OS installation, dividing the physical hard drive into a number of logical discs to improve data storage and retrieval. The benefits of virtualization include increased virtual machine (VM) security, higher speed and efficiency from resources in the already-installed computer components, and CPU virtualization. A malware attack or other software error on one VM won't have an impact on other VMs since they are conceptually isolated from one another. The digital twin differs from the traditional model in that it not only describes a physicalobject but also communicates with it in two directions. On the one hand, the physical object's state is sent to the digital twin so that it can be corrected in real-time. On the other hand, judgements about the physical item can be guided by digital simulation and the outcomes of optimisation in the digital realm. Therefore, a major component of digital twinning and a crucial approach to guarantee the state of synchronization between digital twinning and a physical item is two-way data contact with the physical object.

The digital twin technique has many more derivative features in addition to its primary ability to dynamically estimate energy usage, which traditional models lack. With the usage of automobiles, the battery's natural aging can result in a loss of capacity, and the motor and other elements also unavoidably increase energy consumption as they become older. Through two-way data transfer, these modifications may also be put back into the digital twin model, which can then forecast both the present and future energy usage of automobiles. In other words, the prediction can be updated based on its own state in addition to being dynamic with regard to external sources. It can estimate energy use as well as instantly determine the health of the vehicle. When the energy consumption difference between the real automobile and the digital twin model suddenly increases and persists for a while, it means the car is having problems or is in danger. In order to prevent a serious accident, the owner can quickly fix the vehicle.

Electric Vehicles: Numerous aspects are interchangeable and intricately interconnected. For instance, the status of the traffic impacts the driver's mental health, and the outside temperature influences the battery thermal management state and the opening and closing of the air conditioner. Among these, the effect of temperature on energy use is a crucial element that cannot be disregarded. The digital twin model used in this study to estimate energy consumption is based on a particular electric car, and it primarily considers temperature as well as a number of other contributing parameters. High energy conversion efficiency, clean energy, low energy costs, and reduced noise are just a few benefits of electric vehicles. The greatest drawback is that they have a less driving range than conventional gasoline cars. The aforementioned fundamental concepts will be used to construct the digital twin model for predicting the energy consumption of electric vehicles. Data regarding the automobile is gathered in the "create" stage. The majority of driving data can be read byexternal devices over the CAN bus, and the entire procedure is well-established in the industry. Electric cars themselves contain a huge number of sensors. The acquired data also includes information on the outside environment, like the wind's direction, the temperature, the volume of traffic, the state of the roads, and so forth. Two transmission steps make up the second phase, referred to as "transmission". The wire gearbox within the car is the first phase. Data from sensors are gathered, processed in advance, and then converted into formats that can be read by CAN messages.

The current 5G technology can be used with remote real-time data monitoring. The third step is "aggregation," which entails saving the vehicle and external environment data that was transmitted in the previous step in a cloud database so that both the real-time data that the sensor is collecting and the historical data from any point in time can be accessed. The building process of the entire conceptual architecture of the digital twin consists of four steps, with "analysis" being the most important. The necessary data is prepared in this stage and combined with different data analysis tools and technologies. The database and model are continually improved iteratively as new data is gathered. In this stage, the fundamental building blocks of the digital twin model of an electric automobile are constructed. The fifth stage, "insight," is to visualize the processed data ina way that reflects the differences in at least one dimension between the virtual model and the study object in the real world. “Action" is the last stage. The physical object is altered on purpose in light of the model and physical thing's differences. The energy consumption data is supplied back to the actual automobile once the energy consumption model, which may be updated in real time, is developed and completely iteratively learned until the model is totally credible. As a result, it is possible to estimate the energy consumption of the automobile with accuracy and to foresee a number of issues or concealed flaws that result in higher energy consumption.

Temperature has a big impact on how much energy electric cars need. Electric vehicle energy consumption basic models, however, are unable to capture the dynamic state of energy consumption with temperature changes when the vehicle is operating in real time. As a result, the next stage is to continuously update and improve the electric vehicle's core energy consumption model. The test vehicle was driven on public roads, and other power-hungry features, such as seat heating, air conditioning, and radio, were switched off when not required. Various test vehicle data, such as time, vehicle speed, SOC, instantaneous output voltage of the battery, instantaneous output current of the battery, acceleration pedal opening, maximum battery pack temperature, minimum battery pack temperature, etc. were obtained using the test vehicle monitoring cloud platform. With the following guidelines, invalid data in the monitoring platform was discarded to make the data more targeted to reflect the correlation between energy consumption and temperature: while driving, if it was necessary to open other power-consuming functions like the air conditioner, the data was discarded when it was opened. The monitoring platform may pick up the ECU signal when a power consumption function is activated. The measured data was likewise beyond the purview of the study when the automobile braked and the energy was sent back to recharge the battery. The monitoring platform shows that the battery's output current was negative at this time. Through testing, it was discovered that when the temperature changed quickly, the vehicle's immediate energy usage varied greatly. The data at the time was worthless for the outcomes since the method is complicated and the error is considerable, thus it was discarded. The temperature change threshold was set at 1 C/100 s, meaning that data was deleted when the temperature change during 100 s exceeded 1 C. It was considered a lengthy stopping time when the speed was held at zero for longer than three minutes, and the data during long stopping durations was also destroyed.

Real-time data uploads allow for the ongoing modification and optimisation of the compensation coefficient, which in turn allows for the continuous improvement of the digital twin model. The future energy consumption of the electric car at various temperatures may be forecasted using the optimized model. The digital twin model is finished as a result. The digital twin model, which validates the viability of the approach, is constructed based on the conventional model in the dimension of temperature-energy consumption. The digital twin model will improve with time, and estimates of actual energy use will become more trustworthy as more real-time monitoring data is accumulated and utilised to change it. Only the temperature effect of the digital twin model of the vehicle energy consumption is changed in real time through the data monitoring platform in this work due to the limitations imposed by the current circumstances. We used the assumption that the model accurately reflected the actual scenario without real-time optimisation for other minor influencing elements like vehicle speed, brake energy feedback, rolling resistance, etc. As the digital twin model develops, gains popularity, and even enters the market, additional factors impacting energy use will be changed in real time. There will be more data required to optimize the digital twin model, a lower sample interval, and a more sophisticated collection, processing, optimisation, and forecasting process overall.

Automotive Production Lines: Meeting the delivery deadline is challenging in car production facilities because unanticipated abnormal events like product flaws and equipment breakdowns frequently occur. The Fourth Industrial Revolution's production innovations are used to overcome this and adhere to the customer's delivery schedule. Recently, the dynamic operational control of industrial systems has been made possible by vertical integration and horizontal coordination—key ideas of the Fourth Industrial Revolution. The adoption of the cyber-physical system (CPS) and digital twin (DT) for improved processing and systematic efficiency of manufacturing assets is also supported by industrial digitalization. Response to unforeseen abnormal occurrences that occur in industrial facilities has been made possible through control, communication, and effective connectivity of the physical and cyber worlds.

An engineering system called a CPS aggregates data from various manufacturing applications and elements in order to improve the performance of manufacturing systems. It then uses this data to forecast the future conditions in manufacturing facilities where abnormal scenarios take place and responds accordingly. By interacting with multiple production locations via data collecting, analysis, and processing, the CPS demonstrates benefits of providing extra optimization and cost reduction, and it aids people in making choices through control or forecasts. Additionally, a digital twin (DT) is a virtual plant that replicates a manufacturing facility, synchronizes its data and operations, and improves the CPS's capabilities by using various analytical findings to forecast the circumstances at the facility in the future. Automobile manufacturers are now experiencing a lot of challenges in achieving the delivery date due to the rapidly changing customer demands. This occurs when numerous different types of automobile bodywork are produced on the same line to meet the demands of various models' brief life cycles. As a result, several facilities are required for each phase since various forms of vehicle body production must be completed. The manufacturing plant has a complicated production chain since a significant amount of machinery is needed. As a result, numerous facilities have failures, which results in substandard products. It is impossible to stick to the manufacturing schedule because of the aforementioned problems.

Evaluation of the manufacturing site performance in terms of issue states, such asmachine failure or famine at the manufacturing site, was used to enhance decision-making in earlier DES-based research on automobile production lines. However, because DES was used, these studies did not take into account the aspects associated with decision-making assistance for foretelling dynamic operational situations through vertical integration and horizontal coordination. In other words, it was challenging to represent real-time data because of the long-term model implementation and model input components. Dynamic diagnosis and prediction were therefore impossible. Consequently, a fresh approach is required. A DT-based CPS meeting the needs of production sites must be built through vertical integration with the industrial Internet of Things (IIoT) and by horizontal connection with engineering applications in order to address the challenges encountered by automakers. To replicate the layout of the production facility, the DT is used. In addition, technical functions are given via prediction and diagnosis connected to the production site through vertical integration and horizontal coordination, which are features of CPS. The function of each component of the manufacturing site is taken into account and reflected in the virtual representation. Therefore, it will be able to take into account and forecast the state of dynamic production sites using real-time data if DT and CPS are used to the car sector.

If manufacturing can be carried out in accordance with the production plan, this will help the decision-making process. In an automobile body manufacturing line when equipment breakdowns and product faults occur, the DT forecasts and decides if production in accordance with the production plan is feasible. Additionally, the DT-based CPS can decide if manufacturing is feasible when the order quantity is altered, for instance, in the case of urgent orders from original equipment manufacturers (OEMs) of automobiles. By accessing, processing, analyzing, and applying data based on the Internet connection between the physical components and virtual element technologies, the CPS refers to a system that improves the operations of physical components. Through the service composition of diverse advanced engineering applications, the CPS advances the processes and operations in the production site based on the physical plant interface by aggregating resources, tools, and goods. As a result of this CPS characteristic, it is clear that a high level of interoperability is necessary in order to achieve the sophisticated system composition that is required in terms of system of systems. The DT may be characterized as an integrated virtual model that replicates various physical environment features while reflecting the information model and functional components. As a result, while building a DT, diverse information must be integrated. It may be characterized in the manufacturing sector as a virtual plant that replicates the configuration of the real plant and synchronizes data and operations pertaining to design, operation, and production. The performance indicators may also be repeatedly obtained to conduct dynamic forecasts and diagnostics, and processes can be improved by being coupled with optimisation or plan-generation algorithms. The consequences of its characteristics on the manufacturing sector might be as follows: It can increase management accuracy and facilitate quicker decision-making for users. To further support the cyber-physical integration of the smart manufacturing paradigm, DT acts as a key technology of integrated systems for the design and administration of plant units. Additionally, it may develop the systems and processes of the complete productionsystem as a concept that can adapt to the full product life cycle.

Due to the existence of several resources used to produce car body goods, the physical environment functions as a real-world manufacturing site with a convoluted production chain. The IoT uses sensors and radio-frequency identification to transfer product and machine information from the manufacturing site to the web-based integrated manufacturing platform and legacy system. To get the proper body form, a different sort of metal mold must be used depending on the type of car. But various metal molds have varying lifespans and have different usage times. Additionally, due to an inaccurate mold adjustment, flaws like wrong forms and fractures may appear in the first phases of manufacturing or during welding. The necessary duration of maintenance also varies for each machine at the manufacturing site since the frequency of failure varies. Even with a production plan in place, it might be challenging to foresee the occurrence of these unexpected events due to their nature.

Establishing a production plan and determining whether production will be achievable become challenging when an urgent order from an auto OEM is received at a manufacturing facility where such anomalies frequently happen. It is typical to create cautious production plans in order to account for the aforementioned uncertainties; yet, this results in losses due to sub maximal production. A four-layered architecture is used to implement the process for the DT-based CPS to deliver services (asset, communication, information, and application levels). A request to validate the production plan is made by the production planner in the assembly lines for car bodies. The manufacturing component of production lines for car bodies, the asset layer, gathers data. The communication layer's protocol and middleware are used to receive the data from the assembly lines for car bodies. In order to create P4R information objects, the acquired data are then consolidated and sent from the communication layer to the information layer. This shows that several kinds of manufacturing-related data are translated to the P4R information model's format, which is needed to drive the DT. The application layer receives the aggregated P4R information objects, and the active DT is created and synchronized. Following DT execution, the information layer receives the production plan's validated outcome, which aids production planners in decision-making. Information is essential to running the architectural framework, and the P4R information model is used to represent the abstract and actual instantiated aspects of the data in the operation's abstract data structure. Class-specific data sources include IIoT, legacy systems, and business solutions. In addition, a data model with object-oriented ideas was created because the CPS uses a lot of data (such as data gathered from the site) and that will help with storage, processing, and indexing. The service component method, which offers pre-predictions based on the production plan, displays the components for driving the DT as well as the interoperable information flow in the DT application. P4R information objects are used by the DT, a key technology that permits communication between the CPS's parts, in the form of the P4R information model. The DT operation module for the service composition method automatically constructs a DT, synchronizes it based on the P4R information objects, runs a simulation, and provides the result values when the DT application is operated on the Web-based integrated manufacturing platform. Functions for data interoperability between the Web-based integrated manufacturing platform and DT are defined in the "Data parsing" class. The basic model, logic, and DES engine are imported by the "Configuration" class to construct a DT. The "Data parsing" class's P4R information objects are retrieved by the "Synchronisation" class, which synchronizes the information according to the DT's base model. A DES execution function is part of the "Simulation execution" class. The production volumes by product are arranged among the simulation results by the "Reporting" class.

Privacy Enhancement: The Digital Twin is a virtual representation of real-world physical objects (entities) that combines a variety of artificial intelligence (AI)-based techniques, real-time predictive analyses, and forecasting algorithms that operate on top of big data collected from Internet of Things (IoT) sensors and collected historical data. Through simulation, future state prediction, and wise decision-making in relation to multiple lifecycle stages, the Digital Twin's ultimate goal is to enhance design and execution in digital manufacturing. The Digital Twin gives manufacturing engineers the ability to monitor the execution of simulated processes created on top of multiple sensor data streams and to gain the insights necessary to optimize the manufacturing processes, enhance product performances on-the-fly, and improve the entire lifecycle. Strong connections between ML and IoT allow for the powerful analysis of several data streams gathered from physical objects and utilized as a basis for testing and prediction. For predictive maintenance, the availability of past data enables ML models to learn the maintenance statuses of assets. However, Digital Twins require a flow of real-time data in order for the ML models to continuously train. We will go through location-based behavioral analysis, temporal behavioral analysis of time series, and ML techniques for supporting behavior and performance modeling in the sections that follow.

The two types of privacy-preserving methods used in cloud computing are non cryptographic methods using a policy-based authorisation architecture and cryptographic methods using encryption algorithms and cryptographic primitives. the most popular privacy techniques for cloud computing digital identity verification. The PRIMA systemis an illustration of a privacy-preserving identity and access management system for federated login that permits a regulated exposure of the private data of the users. Smart vehicles are made to help drivers in many different ways, from enhancing their user experience (such as lane change, parking assistance, night vision, traffic sign and traffic light recognition, map navigation support, etc.) to lowering driver distraction and enhancing their safety. Cloud-based technologies are nonetheless susceptible to a huge attack surface, partially through client apps and even more so through a variety of assetsthat may be attacked. In this part, we construct a scenario based on a digital twin that emphasizes data sharing about assets and operation lifecycle processes in the automotive industry. The obtained data could include private information that has unforeseen, unwanted effects on the subject's (driver's) privacy. The purpose of the scenario is to show how the Digital Twin can be used as a privacy enhancement tool that links dynamic privacy data to the services of different stakeholders, generates new insights into privacy parameters, and identifies privacy anomalies that can then be automatically reported back to the subjects. As a means of enforcing the GDPR, the design and implementation of the Digital Twin toolset are subject to a number of requirements, including the establishment of an efficient infrastructure for data collection, the development of data models to support data management for stakeholders and assets, and the creation of privacy metrics and knowledge bases with implemented rules and policies, such as GDPR requirements. The majority of connected infotainment controls in smart cars gather a variety of personal data, from information about driving behavior and habits that can be used for analysis and driver-specific setting adjustments to on-board sensor navigation systems that provide precise location information and information about where and how long the car has been parked previously. In order to design their plans with special offers and discounts and to put new offers in a way that is advised by monitoring systems, advertising and insurance firms use the driving habits that may be determined based on the personal data that has been acquired.

Such information can be further analyzed, merged, and connected with other sensitive data, such as bank account information, health data, etc. In order to facilitate further customisation of smart vehicles and improve the driving experience, the privacy scenario is built to gather private data from the Advanced Driver Assistance System (ADAS), which analyzes driving patterns, common routes, and driving behaviors of the drivers. A smart automobile is made to be handled at the edge, collecting different warnings andstatuses determined by the vehicle's internal sensors. The Digital Twin stores all the data pertaining to the operational driving status of the vehicle in the cloud, including its manufacture and operational history, and then communicates this data to stakeholders. Operational effectiveness and automatic driver feedback are made possible by the Digital Twin's real-time knowledge into the operational driving states. The purpose of building the Digital Twin demonstration was to identify and analyze privacy data, improve relevant privacy-by-design processes, and enable GDPR compliance as edge and cloud computing raise security and privacy challenges. Overall, choices on potential privacy concerns associated with the operational driving lifecycle should be made more quickly and intelligently. Any operation carried out on a smartphone and any data kept within run the danger ofbeing altered and accessed improperly. Various stakeholders, including service providers, behavioral marketers, companies that use geotagging to include location information in posts and images, insurance providers, etc., can access privacy data collected by smartphones. The Digital Twin was created with the goal of improving real-world products and processes based on simulated data and ML supported decisions. It is a virtual representation of the real-world manufacturing, operational, logistic, maintenance, and even administrative processes related to either a company or a product. The developmentof the Digital Twin demonstrator for the automotive industry and smart cars improves the general functionality of the vehicles, including their security and safety, while privacy data must be kept secure in the cloud and must adhere to privacy policies, procedures, and laws such as the GDPR, the NIS Directive, and the eCall alarm system at the European level, as well as laws at relevant national data protection laws.

CONCLUSION

Particularly, production based on client orders must be planned cautiously because of problems such product failures, equipment failure, maintenance, initial adjustments, and production settings, which results in losses from submaximal production. The status of the manufacturing site and the production plan must be manually represented in the simulation in such instances, therefore existing studies that check and forecast production plans have limits in the case of quick prediction. Failure to get around these restrictions may result in a delivery being delayed or losing potential customers. With relation to the operation and production at car body production lines, this framework can improve the prediction's effectiveness. A service composition process using a Web-based integrated manufacturing platform based on the DT is offered by the DT-based CPS. Additionally, a data model for DT operation as well as a P4R information model for automobile body manufacturing lines were given. This study can act as a model for future studies on the application of CPSs in the automobile sector. Instead of the P4R information model for automobile body production lines utilized in this study, future research must concentrate on the creation of an information model for DT operation that can be applied in general manufacturing. In accordance with the information model of the whole manufacturing sector, a class diagram must also be created for the DT operating module.

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