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DIGITAL TWIN IN RAILWAY APPLICATIONS

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Abstract. *The railway is a huge system with several subsystems, and in recent years, with its modernization and development, it has become even larger and more complex. Railway infrastructure and rolling stock require attention from the aspect of maintenance, monitoring and management. Digital Twin (DT) technology with implemented advanced technologies such as IoT or Artificial Intelligence can respond to a large number of requests coming from the railway. The railway provides space for successful application of DT technology, the aspiration to digitize the railway and reduce costs, optimize the operation or simulate any activity before it is actually physically implemented. This approach has become increasingly popular precisely as it has reduced the time and improved the system. This paper aims to show the current application of DT in railways, and its benefits and attractiveness for railways.*

Key words: *Maintenance, monitoring, Digital trains, Rail turnouts, ERPS, Digital model*

1. INTRODUCTION

According to a report by the market research company Grand View Research, the global digital twin market size was $7.48 billion in 2021 and is projected to grow at a compound annual growth rate (CAGR) of 39.1% from 2022 to 2030 [1]. DT is a virtual representation of a physical object that is primarily based on the data exchange between the virtual and the physical model. Data exchange, Fig. 1, or communication depends on the maturity of the DT and it can be one-way, as when the physical model sends signals and data to the digital replica, or two-way communication when the virtual replica and the physical model exchange data, when the full communication between the two objects, physical and digital, is achieved [2]. The real time data exchange allows real time monitoring of the physical model. Data collection takes place through sensors that are positioned so that they can measure values needed to track a specific physical object, process or system. By analyzing the collected data in real time via artificial intelligence or other methods, it is possible to detect certain failures or indications that they will occur in the future [3].

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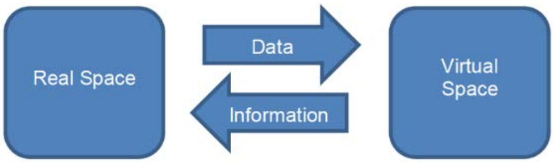

Fig. 1 Information (data) exchange between Real Space and Virtual Space

In addition to artificial intelligence, the basic technologies that enable the creation of DT are Internet of Things (IoT), VR/AR, Cloud Computing, Communication (protocols, Standards, 5G and 6G networks, etc.), Hardware and Development technologies [2]. The application of DT technology in industries is increasing. The reason is the advantages that DT technology brings; the purpose of application is reflected in the possibility of optimization, quick and easy decision-making, remote access, real-time monitoring, security and maintenance of certain processes, systems or objects. Industries which apply DT successfully are: Aerospace, Manufacturing, Healthcare, Energy, Automotive, Petroleum, Public sector, Mining, Marine, and Agricultural [4]. According to Thomas [5], predictive maintenance also requires a strategy that would consider the railway system as a whole, that is, connecting all data from individual components in the railway system. This indicates the need to use digital twin technology. The aim of this paper is to give an overview of the current applications of DT technology in railways. Successful applications of DT technology in railways show the benefits of the railway digitalization.

2. Application

The Siemens Mobility company has developed the Railigent mobility program package that enables a holistic approach to a railway system, covering the entire value chain, from data transmission to their analysis and feedback. It enables monitoring, diagnostics and improvement of railway assets. The core of this software package is MindSphere, an IoT operating system from Siemens [6]. The Railigent program package is designed to include the infrastructure and vehicles (rolling stock) of the railway. By data collecting and proper analysis, it is possible to ensure maintenance and increase operability. The challenges that Railigent faces are the large amount of data collected, the synchronization of data collected with vehicles (wheel profile condition, braking behavior) and track data (track damage) [6].

The development of smart algorithms for data processing supported by sensors enables smart diagnostics that can detect any anomaly or error on the bogie and assess the condition of the bogie itself. Intelligent Diagnostics aims to show real time behavior and possible changes to bogie due to dynamic influence. By monitoring and analyzing the measured signals obtained from the sensors on the bogie, maintenance can be significantly affected, by predicting the time for the replacement of individual components on the bogie via the analytical model, and detecting possible malfunctions [5, 6].

2.1 Railway bridges

Researchers from Cambridge University in collaboration with partners Network Rail, Microsoft and the Alan Turing Institute are jointly developing a system for monitoring the condition of bridges in Great Britain. Many bridges are old and near the end of their designed service life. For these reasons they represent a critical structure in the railway infrastructure that needs to be monitored and controlled. By applying advanced BIM modeling, the finite element method, real-time data analytics and a combination of different sensors for measuring physical quantities from which a large amount of data is obtained (Fig. 2), it is possible to create a DT of bridges based on physics and real measured data through sensors for carrying out structural analysis and capacity assessment of bridges [7].

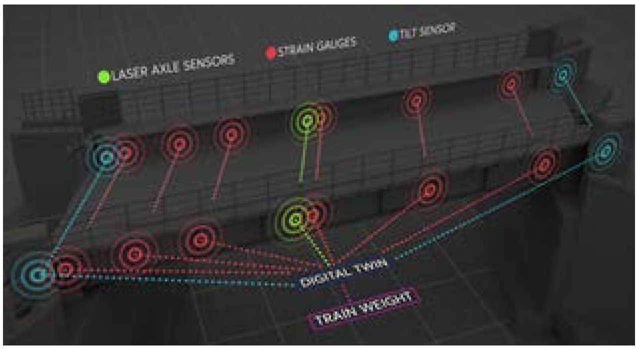

Fig. 2 Digital twin based on measured data [7]

Based on the sensors and algorithms of the system and the deformation response of the moving train (Fig. 3), it is possible to predict the axle weight of the passing train. The collection of such data enables the control of overloading, stresses and deformations in the bridge structure. With a sufficient amount of data it is possible to generate an accurate digital representation of the bridge structure. Analyzing the structure of bridges throughout their entire life cycle provides engineers with useful information for planning safety and proactive maintenance programs and optimizing future design [7].

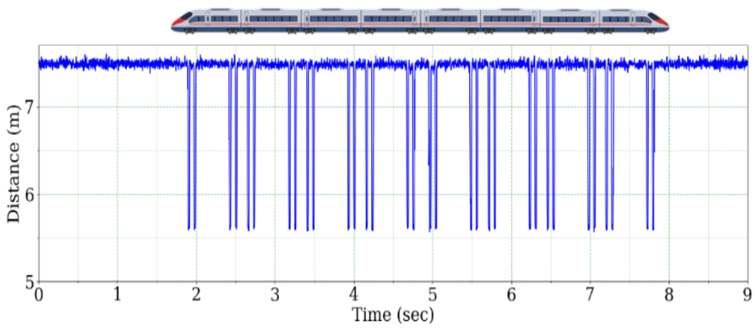

Fig. 3 Deformation response of the bridge [7]

2.2 Digital Trains

The company Digital Virtual Reality Systems, Fig. 4, has developed Digital Trains that brings together the Digital Twin of individual elements, including dynamic simulations that correlate with test results. Simulations include: Route profile and tracking, static and dynamic measurement, track quality assessment, dynamic simulations with rail-to-wheel contact, derailment and collision research as well as consumption [8].

Digital Trains can be used to design collision energy management systems, understand vehicle performance under normal vehicle operating conditions, and how the train connects to the rail infrastructure. DT and simulation results are easily shared with others, making this an effective collaboration tool for project management, training operators and products to visualize, understand and optimize performance [8].

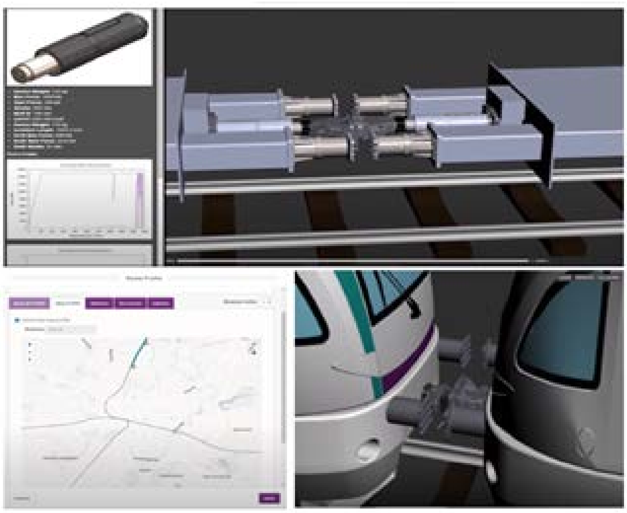

Fig. 4 Digital Train Software [8]

2.3 Rail Turnouts

Railway Turnouts (RT) are critical points on the railway infrastructure. In cases of simultaneous occurrence of high or low values of the periodic mean temperature and close to zero value of the second temperature difference indicator, there is a probability of failure. Failure is the possibility of cracking (which can penetrate deep into the rail and lead to its breakage) or buckling of the track. Because of this, there is a need to ensure the correct technical condition of RT and their components, which requires certain measurements and data collection on the temperature change between the rails temperature and the stress-free temperature (SFT). The system for measuring real time temperature differences and visualization enables the application of DT for monitoring the condition of RT from those aspects. The system for measuring rail temperature differences is shown in Fig. 5 and includes a UbiBot WS1 WIFI wireless temperature logger and an external DS18B20 temperature sensor integrated into an S49 (49E1) type rail as Tszyn WS1 WIFI [9].

Fig. 5 Measuring station Tszyn WS1 WIFI with rail type S49 (49E1) [9]

The method is based on measuring the internal head temperature of the S49 (49E1) rail using the UbiBot VS1 WIFI wireless temperature, humidity and light recorder equipped with the external DS18B20 temperature sensor integrated into the S49 (49E1) type rail, as it is presented in Fig. 6. The measuring station provides data on the ambient temperature, humidity and ambient light [9].

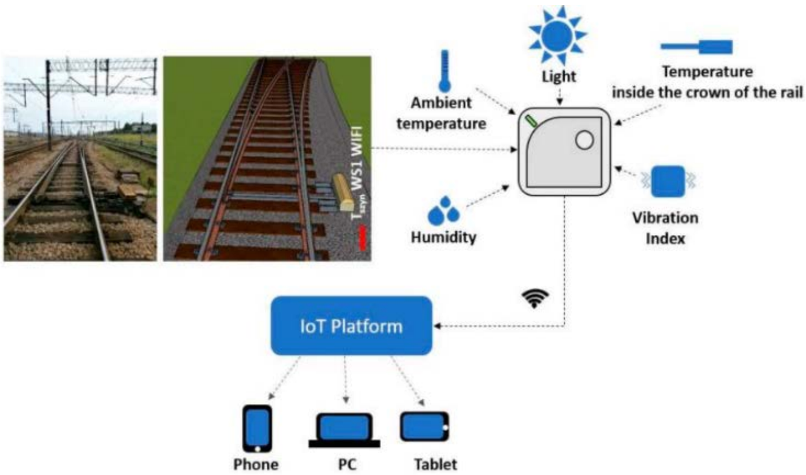

Fig. 6 Measuring system with IoT Platform on RT [9]

2.4 Electric Railway Power Systems

DT technology has successfully adopted the highly complex Electric Railway Power Systems (ERPS). The DT technology concept for the adopted ERPS is shown in Fig. 7. The application of DT and the development of various simulators is important, especially when it comes to monitoring the main circuit of the railway system, from the aspect of current and voltage levels at certain points. On the other hand, the ability to see not only one part, but the entire system, makes DT technology more attractive.

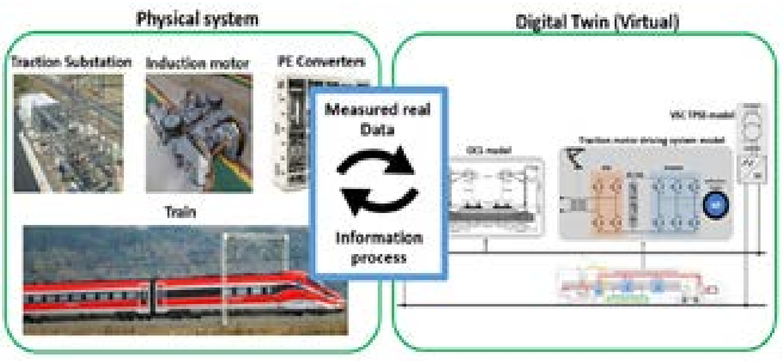

Fig. 7 ERPS representation of a physical system in a digital twin [10]

The implementation of a digital twin (DT) can ensure the correct operation of the monitoring and control function. The main application of DT in this area is [10]:

Energy management, ERPS is a huge and complicated high-power network. The connection between the renewable energy sources and the energy storage system, makes the energy control system more complex. This communication between different layers can be implemented by the Internet of Things (IoT) using DT technology.

Power flow analysis, analysis of energy flow in various parts of the network and in sending feedback. Application of DT for power flow optimization is required.

Fault diagnosis and maintenance, the railway has multiple systems that have their own control units, different types of sensors that are exposed to mechanical vibrations and electromagnetic interference. By applying offline simulation, one can determine system faults and errors. The DT concept represents an ideal platform for such a purpose.

Condition monitoring aims to provide prediction of any destruction of the electrical equipment, fault diagnosis and maintenance of the ERPS infrastructure.

Timetable management and Operating profile optimization. Using DT in real time enables an accurate timetable, better planning and monitoring of railway traffic. Optimization of the operating profile aims to reduce energy consumption and increase system efficiency.

3. Benefits

With the development of computational resources and the increase in data storage and the development of communication technologies with artificial intelligence application, it is possible to create a DT that would create a strong connection between a digital and a physical object [11]. The benefits obtained through the connection enable a more precise visibility of system functionality. With such a real-time connection, it is possible to optimize and reduce system errors, predict future failures and anomalies based on the collected and analyzed data. The possibility of monitoring the life cycle of a certain system can show the operation behavior of the system and detect failure patterns, which significantly contributes to the improvement of the design, functionality and reliability of the system. DT technology enables interaction between systems, and the ability to make decisions based on current data.

4. CONCLUSION

The DT concept requires the knowledge about the physical behavior of the system. With data collecting and sensors in the right place, it is possible to analyze the observed system. DT realistically shows the current state of the system based on measured values by sensors and actuators which control the system. The potential of DT technology is mainly in the holistic view of a complex system, more precisely in connecting several sub-systems into a final one. This way, simple monitoring of all subsystems, effective optimization and predictive maintenance can be achieved. It is important in the railways for DT to constantly refresh the collected data. On the other hand, creating a DT for a holistic approach also means investing more energy and effort in implementing the DT and its application. In this paper, examples of DT on certain sub-systems in the railways are given. One can notice that the applied models are very simplified and oriented towards the critical points in the systems. Future directions of research should include the creation of complex DT models in the railways that would give a full holistic view of the system. Attention will be given to the synchronization of data exchanging between a physical and a digital model.

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