Digital twin for the integration of the automatic transport and manufacturing processes

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Abstract: Simulation techniques for time calculation in industrial transport are not currently deterministic. This supposes a time uncertainty in production planning with economic implications. The digitization promoted by Industry 4.0 allows the automation of transport in manufacturing processes. In this way, the Automated Guided Vehicles (AGVs) performance can be simulated to obtain more accurate results. The definition of a virtual simulation environment through digital twins is an incipient area of research in this field. Digital twins achieve this purpose without intervening in the physical world thus minimising costs. In order to facilitate the use of digital twins, in this paper, we implement a web-based simulation service to improve the user experience. The user will be able to pose hypotheses and visualise the execution in real-time. The techniques implemented for the simulations are based on Robot Operating System (ROS) within the Gazebo environment, IIoT communications require the Node-network programming environment which is in charge of the hyperconnectivity and the creation of the user interface.

Keywords: AGV, Industry 4.0, Digital-Twin, ROS, Simulation.

1. Introduction

The fourth industrial revolution is characterised by the digitalization of processes and machines. Digitization allows connectivity between elements, generating data with every action. The information must be stored for later analysis, which is known as Big Data [1]. Industry 4.0 seeks the sensorization of processes with the use of Cyber-physical Systems (CPS)[2], which serve as an intersection between the digital environment and the real or physical world. CPS are identified by their ability to communicate with other elements through the Industrial Internet of Things (IIoT) [3].

Moreover, digitization helps to create traceability of products [4], not only on the production line but also throughout their lifetime. Traceability provides feedback on the quality of products and their relationship to the manufacturing process. In this way, potential problems can be analysed to improve methods and processes.

Furthermore, unplanned stoppages in production processes are costly. Predictive maintenance [5] reduces these stoppages thanks to the data offered by sensorization. The knowledge generated by the information is crucial to anticipate failures.

The sensorization of the machines and Big Data generates the necessity of creating a computing environment within the Industry 4.0 ecosystem. The connectivity of the CPS makes it possible to
integrate with cloud services.

At this higher level, communications with other external services to the organisation (e.g. logistics, suppliers, administration or inventory) take place, which is usually referred as hyperconnectivity. However, an increase in connectivity also implies a greater vulnerability to cyber-attacks. For this reason, cybersecurity is critical to ensure the integrity of communications.

The creation of this digital ecosystem enables the incorporation of new industrial organisation techniques. Real-time communication together with the use of algorithms allows for improved action-taking at all levels. The new philosophy in the industry includes the management domain [6]. More data, knowledge and tools drive improved decision making. The connectivity of the production line encourages automation of management tasks (e.g. inventories, customers, marketing or purchasing).

The creation of models for online production establishes a basis for simulations [7]. In this sense, the possibility to analyse hypotheses and plan future changes reduces implementation time and costs. Hence, the application of virtual representations for identifying unplanned problems, thus decreasing the uncertainty of any change.

Therefore, the main objective of all these technologies and their connectivity is to create added value to the products, increase the productivity and optimise the costs. Digital twins are simulations that allow real objects to be transferred to the virtual environment [8]. The data generated in the processes serve as a link to the virtual models. The purpose of these simulations is to parameterise the models to find solutions to any possible problems. Besides, various hypotheses can be established to understand the response of the process. Digital twins allow the data extracted from the simulation to be analysed to evaluate decisions in future real implementations. With this tool, it is possible to optimise processes without the need to intervene in the real world, thus saving costs.

Implementing new virtual reality [9] or augmented reality technologies means moving from simulation to virtualisation. The implementation of these techniques reduces costs and improves the experience.

Digital twins also apply to the field of process planning [10]. Measuring times is important to have an accurate prediction in order to analyse the economic impact [11]. Changing process conditions produces different results. Due to digital twins, process optimisation is achieved without the need for testing or investment in physical resources.

Within process planning, transport is becoming increasingly efficient due to sensorization and connectivity of all processes. The introduction of intelligence to the optimisation of actions reduces the time and costs associated with transport.

The infrastructure of Industry 4.0 technologies makes it possible to automate transport. Automated guided vehicles (AGVs) are the CPS of mobility in the industry [12]. The connectivity of AGVs based on their sensorization allows for adaptation and integration into the digital industry paradigm. Simulations allow new scenarios to be recreated without risk. However, the lack of widespread implementation and the difficulty of using digital twins including AGVs is a barrier to the simulation of automated transport in the industry.

For this reason, the objective of this paper is to develop an experimental environment to establish the correlation between the virtual model and reality. For this purpose, we developed a communication architecture to integrate the DT data with other industrial systems (e.g., SCADA, MES). Furthermore, a web interface is developed where DT simulation data can be controlled, monitored and exported. In this sense, the human will be able to control the virtual environment improving the user experience. In this paper, the transport problems we addressed by creating an intuitive simulation interface. This interface will be the link of the simulations that are based on the Robot Operation System (ROS) environment Gazebo which is used as the graphics engine. We apply the Node-Red platform, used in industrial environments [13] for the communications and hyperconnectivity regarding the Industrial Internet of Things (IIoT). The cybersecurity is covered through the definition of an architecture for the real implementation and future comparison of the results with the digital twins. A virtual environment identical to the real conditions will be developed to make the simulations more realistic.

For the simulations, we used the AGV model MIR100. A repository [14] containing its 3D model,
the navigation libraries and the default configuration parameters of the vehicle enables the reproducibility of the results.

The remainder of the paper is organised as follows: Chapter 2 defines the problem emphasising the shortcomings and difficulties of digital twins. The proposed solutions are introduced in Chapter 3. The solution requires the creation of an architecture in which the simulation service is considered. In the same chapter, the technologies used for the simulation and the relationships between them are explained. Chapter 4 presents the results and Chapter 5 concludes the article.

2. Problem definition

Currently, most of the methodologies for calculating AGV travel times do not take the environment into account [15]. Besides, there is a multitude of variables that condition the transport time, thus increases the difficulty of simulations (e.g. the layout of the industry, variable obstacles or user instructions). Furthermore, the different algorithms used in navigation condition the resolution and the route, modifying the final time.

The lack of a server sending orders and task automatically, makes it difficult to simulate complex applications. In addition, the absence of data processing and storage capacity is a limitation for analysing the results. Moreover, the lack of connectivity proves arduous for exporting or importing data to other applications.

Therefore, code editing is required to set new targets [16] in most simulations. The requirement of code editing along with the absence of a user interface makes it difficult for non-experts to use this kind of application. Moreover, the current software on the market is expensive and does not always allow massive data export [15]. Additionally, most simulation environments lack a real-time display, which proves negative for the user experience.

Commercial industrial planning applications are not able to fully model the behaviour of AGVs. They result unable to remotely connect to other equipment and prove not compatible with all devices. In addition, the impossibility of importing data from the cloud to check the efficiency of optimisation algorithms is a major drawback. These shortcomings of commercial applications generate the need to create a new simulation environment in this paper.

To date, no simulation techniques have been applied regarding the dynamic environment of the industry. The new development proposed in this article enables the modification of the environment during runtime and simulate real cases. With these techniques [17] it is possible to evaluate configuration changes such as maximum speeds, navigation parameters, restricted areas, etc.

3. Proposed solutions

This paper proposes a global solution by creating a service and communication architecture to create an experimental environment. The main objective is the simulation service and its integration with the rest of the services. Within the simulation environment, communication between different applications is required to create a user interface.

![Simulation environment](image)

Figure 1. Diagram of applications and libraries used in the simulation environment.
In the ROS application, both the AGV (i.e., navigation libraries) [18] and the environment (i.e., Gazebo) [19] have been modelled. Gzserver is an application that creates a web interface to the Gazebo programme, allowing it to be included in the Node-red interface. In addition, the Node-red server operates as a gateway allowing communication between ROS and other external services (e.g., Cloud computing, database) as shown in figure 1. In order to improve the performance of the service, all these applications are run from the same computer to minimise any latency in sending data among applications and the libraries.

![Diagram](image.png)

**Figure 2.** Communications and services architecture for an experimental environment.

### 3.1. Communications architecture

In order to create a real experimentation environment with all the properties of Industry 4.0, a novel communication architecture is proposed. The implementation of this architecture proves advantageous for achieving maximum connectivity and security. The Ethernet-based network is established as the platform and medium for communications between devices. Ethernet networks [20] are characterised by the following features:

- Low latency required for control applications with a high sampling rate.
- High bandwidth for image and video-oriented applications. Scalability to allow connection of multiple devices.
- Communications and network security. Ability to segment networks and tunnel traffic.
- Compatibility with a wide range of industrial and non-industrial devices.

As shown in figure 2, the architecture is divided according to the equipment locations:

- **Remote location:** It allows the monitoring and control of the industrial plant. The simulation server can also be accessed from this point.
- **Simulation service:** It is a server connected to the network with internet access, which is connected by opening ports in the router.
- **Industrial plant:** It is located within the network of the Universidad de León, it has a router with a firewall and Virtual Private Network (VPN) server to tunnel the traffic. This network can be segmented into Virtual Local Area Networks (VLAN) and enable wireless connectivity via WiFi.
Virtual network segmentation using VLAN technology allows sub-networks created to prevent external access into other network services. Traffic tunnelling between the industrial plant and external equipment improves the integrity and security of communications.

3.2. Simulation applications (ROS)

The ROS ecosystem is used for simulations in the field of industrial transport and robotics. ROS provides the necessary tools to communicate with the different sensors and actuators of the AGV. Several ROS libraries allow the communication and control of the AGV. In this case, the same libraries of the MIR100 [14] are used to be able to compare the behaviour of the automatic vehicle. The operation of ROS is based on nodes [21] and the communication is established through the publisher-subscriber philosophy. Nodes subscribe or publish in communication channels called "topics". Each node corresponds to a programme or service and communication takes place between nodes. The compatibility with all the elements is guaranteed through the message structure. This fact makes the information independent from the programming of each node.

For the analysis of the AGV performance, a simulation environment [17], is needed, which is called gazebo. This environment must be dynamic and capable to simulate the data with the sensors depending on the environment. Gazebo has a graphical visualisation engine through an interface that runs locally. To be able to export the gazebo interface, another server with a web interface is created. This server communicates bidirectionally with the original application.

Regarding the interface, the environments are modelled. Besides, elements can be added in real execution time to analyse the behaviour of the AGVs dynamically. The simulation environment counts the number of cycles and sets the real-time in the simulation because depending on the hardware it will take more or less execution time.

![Figure 3. Task scheduling flowchart for Node-network simulation.](image)

3.3. Node-red server configuration and programming

The communications between ROS and the server requires the "contrib-ros" library. There are also Application Programming Interfaces (APIs) [22] in order to provide the simulation with hyperconnectivity, such as the use of email or Telegram among other communication services.

To ensure cybersecurity, access must be established through credentials (i.e. user, password) on the server and also on the interface. Besides, the permissions of each user can be configured.

Several tasks have been programmed to be automated for the AGV. These tasks consist of a sequence of targets to analyse journey times and improve production schedules. Thanks to the automation of tasks...
and time measurement, the software created allow the user to set up different scenarios without the need for programming. It is also possible to import data on production times to calculate the total production time. Figure 3 shows the flowchart of the scheduling performed.

3.4. Proposed simulation interface for Industry 4.0

The purpose of addressing the simulation within the Industry 4.0 paradigm motivates the creation of a local server which allows a link between the user and the virtual world. This server has the ability to communicate the data flow of the model and the user at the same time. Therefore, this server is provided with hyperconnectivity [23] with other third-party applications. Additionally, the user interface is programmed on this server so that the AGV can be controlled.

The programming of the interface is based on Node-red, which is a flow-based programming environment designed for IoT and IIoT connectivity applications [13]. The "node-red-dashboard" library creates a web server for interfacing with multiple users simultaneously from any browser.

The flow editor is accessed from a web browser, being possible to program from multiple devices, and any location. Libraries and APIs are downloaded and installed from its repository. Programming is node-based and each node is a function and can be configured which can be further configurated, being the messages between nodes structured in JSON format. The addition of the gazebo interface to Node-red requires creating a web server in ROS called gzserver. This server runs on localhost, so it can be accessed from the browser. For user convenience, this page will be embedded in the same interface created before.

4. Results

In this article, the main results of this research involve the generation of a communication architecture between different services and the industrial plant following the principles of Industry 4.0. In turn, the simulation environment communicates with the application services, giving rise to a new framework for experimentation.

The communication architecture, based on Ethernet, generates a robust, reliable and scalable network, ideal for the development of an experimental environment using industrial internet platforms. The architecture proposed in this paper has been successfully implemented, allowing intercommunication between the simulation environment and the AGV in the industrial plant.

Furthermore, this network infrastructure enables to connect to other external services. Given the opening of the industrial network to the outside world, cybersecurity and integrity of communications have been considered with the use of VPNs.

The creation of a user interface facilitates the use of these technologies. Communication between the different applications is essential to provide the interface with the information and the ability to act.

The interface has several panels: one panel reports the AGV parameters in real-time (i.e. speed, mission status or position), and on it, there are buttons for navigation to predefined targets including a joystick for manual control, and simultaneously on another panel, the environment in which the AGV is moving is displayed, being able to incorporate new obstacles in real-time as shown in figure 4.

The interface also includes a panel for the configuration of the simulation as shown in Figure 5, where the user sets the objectives and the priority of the processes. Once these are sent, the server will automatically establish the instructions to the AGV. In the implemented interface, both simulation and experimental times are displayed on the same panel while running the simulation.

With this interface, the ease of use and real-time communication with ROS is proven. The unification of the technologies achieves a better user experience. Another advantage is the grouping of applications in a single interface, making it easier the use the digital twins in the industrial plant.

Given the results, this work provides a new platform for communication with the digital twins. The web server manages to classify the information and its processing, so as to carry out actions automatically. The architecture allows connectivity from any point, guaranteeing cybersecurity. In short, a tool capable of establishing a link between the virtual world and the user to improve simulations within Industry 4.0 is archived in this paper.
Figure 4. Parameter information panel and 3D virtualisation of the AGV with obstacles.

Figure 5. Process planning interface for transport time analysis.

5. Conclusions
Digital twins are part of Industry 4.0 technologies. However, their connectivity and applications are still in an early stage of research. For this reason, in this paper, we provide connectivity to digital twins oriented to automated transport in the industry. The achievement of this goal requires a communication architecture which has been created for the different environments for its real implementation. Therefore, the simulation environment proposed results from the union of different services and applications (e.g. ROS, Node-network, Gzserver). The communication between services and applications allows the automatic execution of actions, the control of the simulation from an interface (i.e. HMI) and the connectivity from any device. As a consequence, the applicability of digital twins for industrial plant virtualisation is improved. Furthermore, this work lays the foundations for the integration of communication methods and compatibilities with other software and technologies. The implementation of AGVs in the industry reduces the risk of accidents due to the possible negligence of workers. Moreover, the advanced navigation systems allow a quicker response to any adverse
circumstances than a human being, increasing occupational safety. The methodology proposed in this article allows us to solve the weaknesses of the simulation of the automated movement of AGVs in Industry 4.0, thus achieving the objectives of this paper.

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