DIGITAL SHADOW SUPPORTED BY AUGMENTED REALITY AND CLOUD FOR THE MONITORING OF AN INDUSTRIAL PROCESS

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ABSTRACT

The development of the new technological tools of the coming industrial revolution enables incorporating intelligent functions to traditional industrial systems; even though this demand increases discretely, it is important to promote the transition to this new industrial era. Therefore, this document describes an experimental study conducted for monitoring the distribution station of a MPS 500 modular production system, which for the project is set as physical twin, and the outcome of modeling it as digital shadow, synchronizing them by sending and receiving data to and from the cloud. For this purpose, once the station has been configured and programmed, a Raspberry Pi single-board computer was implemented to acquire the digital signals from the station sensors, and further process and send them to the cloud. For modeling the digital environment, it was replicated in the Blender software according to the area, length and diameter of the elements that constitute the station. At last, the synchronization between the environments and the visualization using augmented reality was obtained programming in Unity and Vuforia, respectively. The results obtained verified that the system matched to the supervision level of the automation pyramid, achieving a latency of 151.23 ms and fulfilling the general purpose of monitoring the station in real-time.

KEYWORDS

Digital Shadow, MPS 500, Augmented Reality, Unidirectional Communication

1. INTRODUCTION

Recently, a significant technological development, known as industry 4.0 (Ciffolilli and Muscio, 2018), has taken place in the industrial area, specifically in the fields of electronics and industrial systems; in industry 4.0, classical production techniques may share operations with new digital tools (Cortés et al., 2019). Due to industrialization in the production circuit, different processes that involve a set of sensors, actuators and controllers, are implemented to enable the plant to fulfill its purpose (Davis and King, 2019); the common denominator of these processes is that they perform automated and sequential tasks (Requena, 2018). The Modular Production System (MPS) is one of these systems since it executes more than one task in real-time to achieve its objective (Villacreses, 2021; Castillo and Guerrero, 2020). Analogously, the distribution station used in this project is an educational laboratory equipment that puts together the principles used in industry industry (Hermann et al., 2016), providing students with knowledge, expertise, and skills to prepare them for a future work environment.

The easiest way to monitor a plant is in person (Jiang et al., 2019), the design of a digital shadow or Digital Shadow allows to obtain a dynamic virtual replica in a unidirectional way (Bergs et al., 2021), when there is a variation in the physical model, the digital shadow automatically recreates these new parameters (Sepasgozar, 2021), that is, the digital environment updates its behavior in the face of any change in the physical environment, but not the other way around, providing any classic process with new virtual, digital and technological resources (Guo, 2019). Data storage in the cloud enables immediate processing and acquisition of the information stored on internet servers, such that it is available for the user independently of the moment or time interval in which he/she requires it; its scalability of reduced costs and accessibility (Alam, 2020) enable that this technology consolidates as a research and development area for the current decade, and both the data storage and data download subscriber functions are mainly used in this project. Augmented reality is another tool that promotes user´s understanding of a specific application but transferring this technology to the industrial field would be considered unnecessary if it is not established the base for its use (Diegmann et al., 2015). For this reason, working on augmented reality over a digital shadow improves the performance being sought, and it even contributes with variables that may guide the operator in a detailed manner (Zhao et al., 2020).

As a consequence of what has been previously pointed out, this paper delves on the procedure to monitor the MPS 500 distribution station using augmented reality, grouping the aforementioned concepts and principles, such that a unidirectional communication system is employed based on the data platform stored in the cloud. In order to accomplish the development of the digital shadow system, it is necessary to model the laboratory station at a real or natural scale. For this purpose, it is initially used a system which is part of the Blender software, that will be further automated using Vuforia and Unity (Hamid et al.,2020) once the virtual environment has been created. A circuit or PCB is made to condition the input signals or the signals from the 24V station sensors connected to the GPIO pins of the Raspberry Pi board (Caiza and García, 2017), such that the data are received, processed, and sent to the Firebase Database platform, to which the station model application is subscribed. This model receives, interprets, and controls the augmented reality application, while observing the performance of the physical and digital stations synchronized in real-time. The paper is structured as follows: section II describes the main concepts and the methodology employed, section III explains the design and implementation, section IV presents the results obtained and section V finalizes with the conclusions.

2. MATERIALS AND METHODS

2.1 MPS 500 Distribution Station

In industry, the modular production system (MPS) is the result of an automated electronic process (Cortés et al., 2019) that consists of sensors and actuators controlled by a PLC S7-300, with a 313C CPU. The distribution station performs three tasks, namely storage, classification, and distribution of a set of pieces or bodies of cylinders, which are classified and distributed according to the color and the material composition. These operation principles are constantly employed in the manufacturing industry (Davis and King, 2019).

2.2 Blender Platform and Vuforia

Blender is a software that can be used for modeling, animation, creation and rendering of 3D graphics (Requena, 2018). It is open source and generally used for graphical design, enabling to model scenarios at real scale with a great level of detail.

Vuforia Unity is a virtual kit that enables the development of software in augmented reality (Villacreses, 2021). It employs planar images as a base for presenting the augmented reality; such images are further converted into a 3D environment to generate the mixed reality effect which, for the case of the project, places the elements of the station and interprets the signals that enable synchronizing the digital shadow with the physical twin.

2.3 Google Firebase Platform

The Google Firebase cloud platform is a cloud-based cross-device digital system (Castillo and Guerrero, 2020), for developing mobile applications and web sites. Its function covers four fundamental pillars such as data analysis, development, growth, and monetization (Hermann et al., 2016). The development group includes the Realtime Database tool, which enabled storing and downloading the data for the system employed. As it was mentioned above, this is one of the tools of the Firebase development group. Its role is to synchronize in real-time the data stored in its independent database; these data are stored in the cloud and are arranged in JSON format, enabling that the data remain updated even when there is no connection, momentarily providing the alternative of publishing or discarding changes stored in the cache until the connection is restored and they are updated automatically (Jiang et al., 2019).

2.4 Realtime Database Firebase SDK for Unity

Broadly, a software development kit (SDK) enables the assistance in the concept, development and results processes, besides solving possible errors (Bergs et al., 2021); for Unity versions 2019.x and above, the connection to the Firebase database is managed from the Realtime native SDK, as opposed to previous versions where it was required to install Google LLC packages from Package Manager to be able to connect to Firebase; this enables the functions for publishing and/or subscribing to the database, and the subscriber function was used in this case.

2.5 Publisher, Subscriber and Data Structure

The syntax that enables the subscriber to obtain the data and the publisher to share them is the JSON structured data format (Alam, 2020). Data are set as objects within the Firebase Realtime Database, and for this reason the database may be defined as a JSON tree, i.e., each node has an associated key, and the set of nodes has an associated ID, such that for the publisher to issue a change in the same database that is received by the subscriber, they should necessarily share the JSON file to enable the communication to be established.

3. DESIGN AND IMPLEMENTATION

The objective of this study is to design a digital environment of the MPS 500 distribution station. Therefore, a digital modeling was made based on the physical station to reproduce its behavior, establishing a unidirectional communication through the publisher and the subscriber, as it is visualized in Figure 1; every subprocess is described in the subsequent sections.

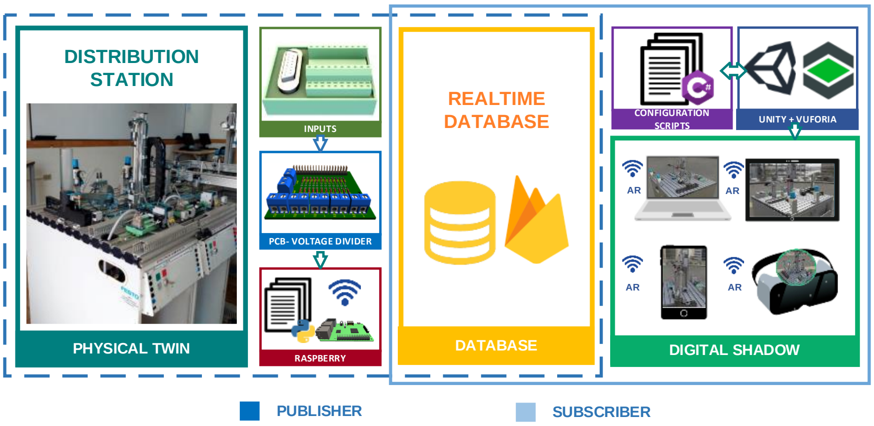

Figure 1. General diagram for the project design

3.1 General Performance of the Station

To implement the operation, the station was automated using ladder programming logic in the Tia Portal software, where each subprocess corresponds to the programmed behavior of the actuators according to the animation mentioned in section 3.8.

3.2 PCB to Adapt the Signals to the Raspberry and Configuration

The Raspberry Pi General Purpose Input/Output (GPIO) pins are adaptable as digital inputs and outputs only at 3.3 V. On the other hand, the station sensors operate with values of 0 V corresponding to logical 0, and 24 V corresponding to logical 1. For this reason, a PCB was built for connecting the input signals; this PCB scales the values of 0 V as logical 0 and 2.9 V as logical 1, since these values can be interpreted by the board.

Once the Debian Buster operating system was installed, the VNC and SSH protocols were enabled to remotely control the Raspberry, as shown in Figure 2. The PIP and PIP3 packet management systems, the GPIO library, Python and Pyrebase were installed through the console of the operating system.

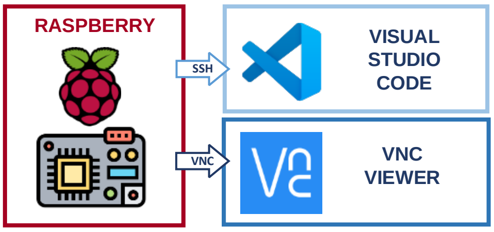

Figure 2. SSH and VNC protocols for Raspberry

3.3 Raspberry as Publishing Element

From the Google Firebase platform, the account was validated with the Realtime Database tool, with the location us-central1 corresponding to Iowa, United States. Subsequently, the JSON file folder and the main file were created in a directory in the Raspberry Pi, in which the Firebase, Pyrebase and GPIO libraries were imported by means of Visual Studio Code with Python as the programming language. The signal of each station sensor was assigned to a GPIO pin and also to a unique node in the database that captured the sensor state at that instant; then, the program was executed, and the first Boolean data were sent. It was also verified at each node that the logical state of the sensors is the correct one. The JSON file provided by Firebase, which is responsible for publishing in the database created, was saved in the same directory as the main file; similarly, to avoid problems, it was verified from the configuration tab that the project data matched the data of the JSON file.

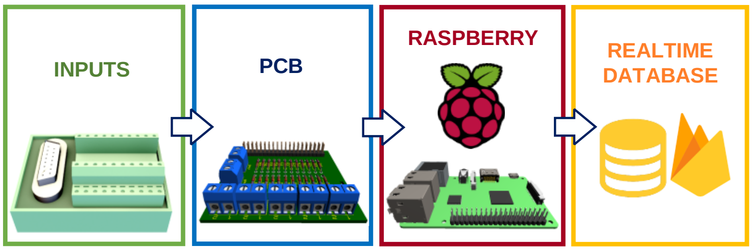

Figure 3. Process that uses the Raspberry Pi as a publisher

As a result of this process, the design presented in Figure. 3 summarizes the procedure, where the sensor signals were published in the platform, each one with its corresponding logical state; then, the data of the sensors that enable the operation of the station or physical twin are published; these data also enable that the digital station or digital shadow emulate its behavior. Subsequently, the digital environment is modeled.

3.4 Evaluation of the Features of the Physical Twin

Prior to modeling the station, it is measured the dimensions of all the elements that constitute it, and it determined their position, arrangement, materials, and all physical features that can be visually captured from every object, including the base of the station.

Once each element has been measured and evaluated, the station is modeled; the entire virtual environment was created in Blender at a natural scale from the real dimensions obtained. The process initiated modeling the sensors, then the actuators; subsequently, textures are imported to the structures of the elements, and finally animation is added to replicate the movements of the cylinders or pieces, exchanger module, elevator module and stacking module; the remaining elements are static, and thus do not need movement, Figure 4 shows the procedure implemented.

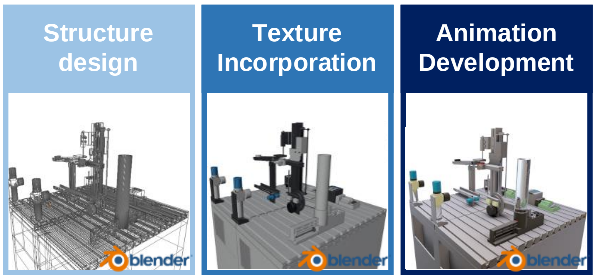

Figure 4. Modeling of the Physical Twin to Digital Shadow

3.5 Integration of Vuforia and Unity for Rendering with Blender

Once the final virtual environment was consolidated, it was imported to Unity as shown in Figure 5; on the other side the input enters as a variable, a QR input in the case of this project, to be further interpreted by Vuforia, which also imports the data from the results obtained from the QR and from the plugins with updated information about the position, amount of light, amount of shadow, among others. After this process was finalized, the file was exported as an executable file for the Android platform.

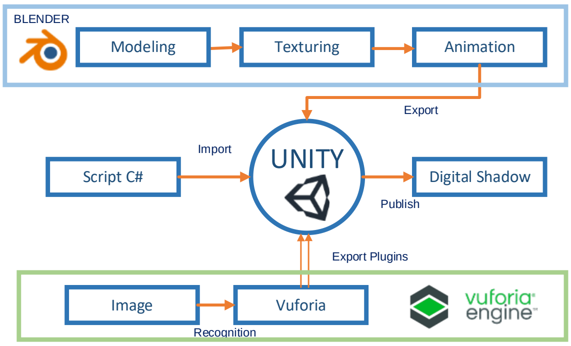

Figure 5. Process for creating the digital shadow with augmented reality

3.6 Collection of Data from the Subscriber

Conditions for developing the animation were established from the model imported by Unity from Blender; these conditions validate that the process of the digital environment is executed at the same time than the process of the physical twin. These variables are stored in the Realtime Database (Martinez et al., 2021), i.e., the ones updated by the publisher in the database, as mentioned in section 3.5. The procedure to obtain these variables is now explained. After the Realtime Database SDK has been imported to Unity and the JSON file has been added, two Scripts were created so that each subprocess is independent: the first was used to control the animation, and the second to download the data from the base. The two scripts were programmed in the C# programming language using Visual Studio 2019. For the download script the Firebase libraries were imported, the JSON file was called and the value of the queried variable was requested honoring the structure of the nodes; in the case of the second script, the data obtained from the first script was requested, the conditions for each animation were received and assigned, it was saved in Unity and exported to a mobile device as an augmented reality app, as can be seen in Figure 6.

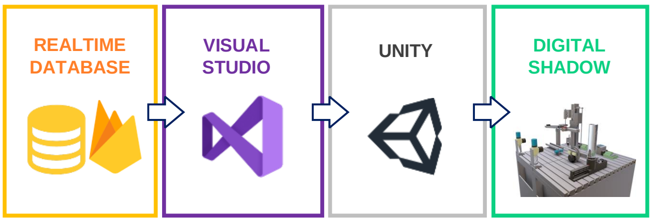

Figure 6. Process for downloading the subscriber data

4. RESULTS

4.1 Evaluation of the Station Model

The environment modeled from the digital twin needs to be understandable and efficient. For this reason, a survey with 5 questions was conducted on 25 people with prior experience in the MPS laboratory; these included graduates, students working in their theses and electronic engineering professionals, because they can be considered as potential operators. The aim was to determine if they considered that the digital shadow fulfilled the requirements formulated in the questions.

The questions were stated as follows: 1.- How would you rate the presented distribution station model? 2.- How do you consider the scaling of the station elements? 3.- How would you rate the realism and definition of the model? 4.- How understandable was the design? 5.- Based on the features observed, how likely is that you recommend the use of the model presented? The responses to questions 1-4 ranged from 1 (Excellent) to 5 (Very Poor), whereas the response to question 5 was in the same range, but 1 represented Extremely Likely and 5 represented Not Likely.

Figure 7 shows the percentage results. It is observed that the station model is accepted, since 66.4% of the respondents rate it as excellent, 27.2% as very good and 6.4% as good; the very poor and regular ratings obtained 0%.

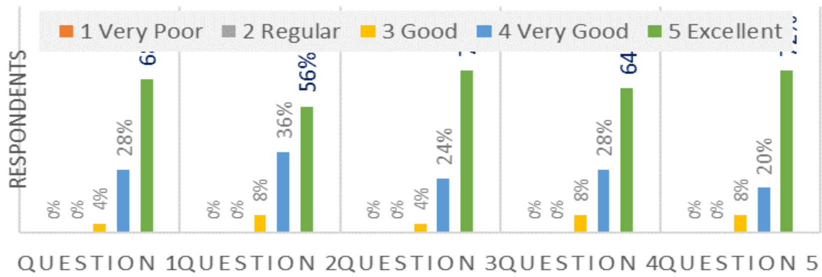

Figure 7. Survey results graph

4.2 Latency of the Publisher and Subscriber according to the Firebase Performance Tool

The data provided by the Firebase Performance tool were considered for a precise analysis. These data included upload and download times for the publisher and subscriber respectively, and relevant statistics and plots, as shown in Figure 8.

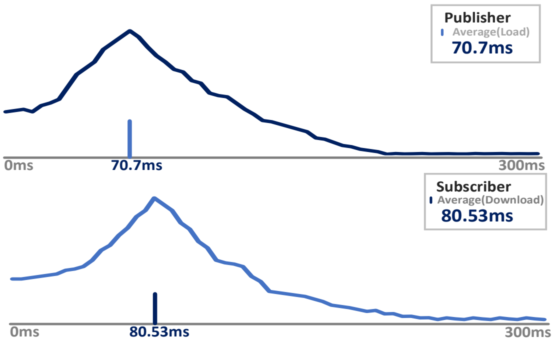

Figure 8. Latency Analysis using Firebase Performance

The total latency of the system is given by the sum of the publisher upload time plus the subscriber download time, which verifies the level of the automation pyramid it belongs to (Mustafa et al., 2019). For the test it was used an IPV4 network with a bandwidth of 20 Mbps, and the subscriber had a Galaxy J7 with Android 7.1 OS, a 1.5GHz processor and a 2.4GHz Wi-Fi connectivity under the 802.11b/g/n standard.

4.3 Performance of the Physical Twin and of the Digital Shadow

The test mentioned in the previous section is now presented. In such test it was verified if the behaviors of the digital environment and the physical twin are synchronized. It was observed that there is an evident delay from the digital shadow; this delay or latency is analyzed in Figure 9. Later, the delay went unnoticed due to a physical effect of the station when, in the physical twin, the exchanger module leaves the cylinder in the elevator module; then, the digital shadow stays ahead and both environments become synchronized again.

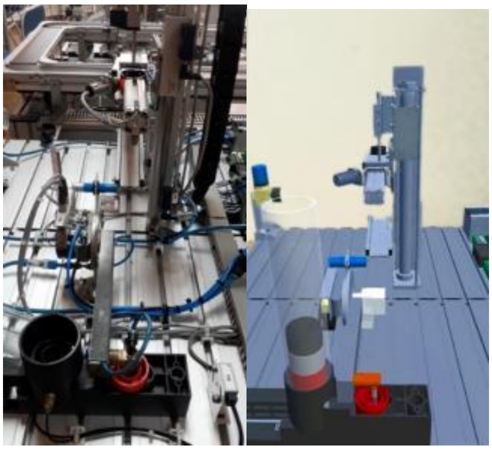

Figure 9. Synchronization of the physical twin and of the digital shadow

5. CONCLUSION

Based on the publisher-subscriber unidirectional communication method described, from the MPS 500 distribution station and the Raspberry Pi board, a digital shadow system was developed that enabled monitoring its performance using augmented reality. The methods employed were developed based on the important contribution of bibliographic material that was collected and analyzed, related to digital shadows for industrial environments. This enabled considering and discarding different alternatives; likewise, the model built in the Blender software enabled that the environment and behavior of the physical twin were precisely designed to obtain the digital environment, such that there is an agreement with the process.

Based on the acceptance obtained from the respondents of the survey conducted, it is important to remark that features such as precision, correct scaling, high design quality and similarity with its physical counterpart, yielded that 72% of the potential operators further recommended to use the way in which the model was built; this enabled to increase the research of this project for another possible application with other station, other laboratory or simply other machinery.

The publisher-subscriber unidirectional communication was used to obtain an agreement in the process, and mainly for synchronizing the behavior between the physical and digital twins. As shown in Figure 8, latencies of 70.7 ms for the publisher and 80.53 ms for the subscriber were obtained; this analysis became relevant when the total latency was classified and related to a level of the automation pyramid. Specifically, this total latency of 151.23 ms corresponds to the third level or supervision level, that is characterized by performing functions such as data supervision, acquisition and storage; thus, it is evident that the process meets the standards associated to monitoring, which is the main purpose.

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