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PAPER

IoT Control and Visualization System with Digital Twins and Augmented Reality in a Digital Transformation Space

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ABSTRACT

This paper describes the use of Internet of Things (IoT) technologies, digital twins (DT), and augmented reality (AR) to raise awareness and disseminate the use of digital services within the INICTEL-UNI institutional project financed by the Inter-American Development Bank to strengthen technological services and satisfy the technological needs of companies, promoting digital transformation in Peru. Within various fields, such as technical education, construction, and manufacturing, challenges are faced related to the adoption of advanced technologies and the need to improve efficiency. The main objective of this paper is to implement an IoT control and visualization system with DT and AR in a digital transformation space. A system is shown to create a technological demonstrator environment that visualizes and monitors sensor data on physical IoT devices in real time, allowing users to interact and operate them through an ESP32 module with data transmission with the MQTT protocol and an AR application developed in Unity and Vuforia. The study results successfully demonstrated the efficiency of real-time communication between the IoT device and the AR application, as well as the efficient ability to perform tasks, validated by users with no prior experience.

KEYWORDS

augmented reality (AR), Internet of Things (IoT), digital twins (DT), IoT device

1 INTRODUCTION

Currently, the adoption and application of advanced technologies such as digital twins (DT), the Internet of Things (IoT), and augmented reality (AR) are applied in various fields, including the construction industry, education, solar energy, manufacturing, supply chain management, and gastronomy [1] [2] [3]. The importance of Industry 4.0, which encompasses a variety of technologies such as artificial intelligence (AI) integrated with IoT solutions [4] and collaborative robotics, is highlighted to transform and improve processes and services in these sectors [5] [6].

It is for this reason that the research is developed as part of the project "Strengthening the services of the CET (Technological Extension Center) "promoting

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the digital transformation of Peru," financed by the Inter-American Development Bank (IDB), which aims to general strengthen the extension of the technological services of INICTEL-UNI (National Institute for Telecommunications Research and Training of the National University of Engineering) to satisfy the technological needs of companies for their competitiveness through their dissemination.

There are technology application problems that include challenges such as the lack of adoption of advanced technologies in technical education, the need to improve efficiency and safety in construction, the search for more efficient solar energy systems, and the integration of collaborative robots in the manufacturing industry [7] [8]. Moreover, some research focuses on creating DT to monitor and control devices in different environments, such as gastronomy. These efforts aim to develop technological solutions and strategies to tackle the challenges unique to each particular context [9]. Research indicates that there is a need to adopt advanced technologies [10] [11], but the lack of adaptation generates a technological lag and the need for a digital transformation. Although specific problems may vary, the need to bridge the gap between the physical and digital worlds through the implementation of cyber-physical systems, DT, and Industry 4.0 technologies is a common theme [3] [12].

The literature review highlights papers that contribute to closing the gap between theoretical knowledge and practice in the construction industry, focusing on the adoption of advanced technologies. In [5], the methodology involves data collection through case studies and analysis of findings to support this adoption, highlighting the overall benefits such as time savings and cost reduction, while in [7], it is implemented in a mixed virtual environment called "Cyberphysical," aligned with the principles of Industry 4.0 in education, also applying this to safety in the industrial work environment [13]. In the case of the implementation of digital manufacturing, in [14], a solution called PERFORM is developed that integrates Industry 4.0 technologies, such as IoT, AR, DT, and 3D printing, using sensors and a micro-Arduino controller to monitor various variables, while in [15], the development of a platform for the monitoring, control, and diagnosis of DT is proposed. Furthermore, in the case of the management of intelligent environments, mixed reality (MR) technology solutions are developed, highlighting the importance of digitalization in the management and simulation of diverse environments, where a solution can focus on intelligent environments indoors [16], while others can focus on industrial gastronomic devices [2].

For this reason, the following question arises: How is it possible to implement an interactive IoT control and visualization system for a digital transformation demonstration space? To answer this question, the general objective is defined: design an IoT control and visualization system with DT and AR in a digital transformation space.

2 THEORETICAL FOUNDATIONS

2.1 Internet of Things

It refers to the network of physical devices that are connected and can exchange data with each other, with systems and servers over the Internet. These devices, which can range from household appliances and vehicles to industrial sensors and medical devices, are equipped with sensors, software, and communication technology that allow them to collect and transmit data [17] [18]. The IoT allows these devices to communicate and collaborate with each other efficiently to perform specific tasks, collect information in real time, and improve efficiency, productivity, and decision-making in a variety of applications and sectors, such as the automation of the home, supply chain management, health, and transportation systems [19] [20].

2.2 Augmented reality

Augmented reality is a technology that combines elements of the real world with digital information in real time, enriching the user experience [21]. Through devices such as smartphones or special glasses, AR overlays 3D graphics, videos, and data on top of the user's real-world view [22]. This enables applications in gaming and entertainment for navigation, education, advertising, and technical support. Furthermore, it generates an interactive way of interacting with the physical environment, merging the real and the digital in an innovative way [23].

2.3 Digital twins

They are virtual or digital representations of real-world objects, systems, or processes. These digital representations are an accurate, real-time copy of their physical counterpart and can be used for various purposes, from design and simulation to monitoring and data analysis [20] [1].

Visualizing sensor data from a physical device in an AR environment can be considered a DT application, especially if it is being used to represent its state and operation. In this case, the DT would be representing the physical object or real-world system, and data visualization in AR would provide an interface to better access and understand the information generated by sensors and other connected devices [24].

In some cases, instead of generating 3D models of real devices, DT can be considered a real-time digital representation of the physical devices connected to an IoT system. This involves maintaining a virtual representation of the devices, their states, and data in the data processing software and web user interface, fulfilling the functions of data representation, real-time updating, simulation, control, and visualization in AR applications [25].

3 PROPOSED SYSTEM

The proposed system is based on the visualization of sensor data from a physical IoT device in an AR environment within a DT context. In this case, AR is used to represent the real-time status and operation of IoT devices to better access and understand the information generated by sensors and other connected devices. The most important components are seen in Figure 1.

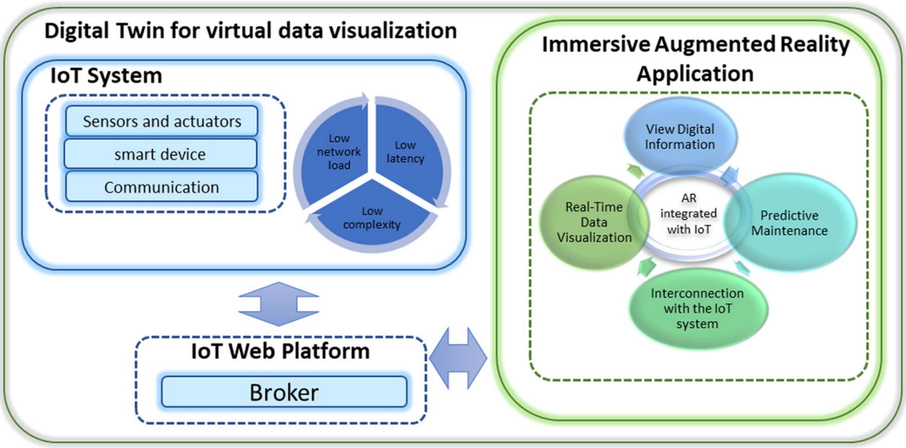

Fig. 1. Scheme of the proposed system

3.1 Architecture

The architecture and specification of the components identified for a technological demonstrator space are shown in Figure 2, organized into: an IoT system (composed of sensors, actuators, a smart device, a communication system, and a web server), immersive application or AR, and the use of DT technology (which is evident based on the creation of virtual data).

This architecture combines IoT, DT, and AR technologies to create a technology demonstrator environment that visualizes and monitors sensor data on physical IoT devices in real time. This combination provides an immersive and functional experience for users who want to understand and operate IoT devices in a demonstration space.

In the context described above, technologies based on the ESP32 module are used, which uses the MQTT communication protocol, for communication with a Blynk service broker for data storage and management. In the case of the AR application, it is built based on Unity, and Vuforia, developing the visual content and interactions in Unity and then Vuforia is integrated for the tracking and detection of identifying elements, which allows overlaying virtual digital data in real time over the mobile device's camera view to interact with the IoT device (see Figure 2).

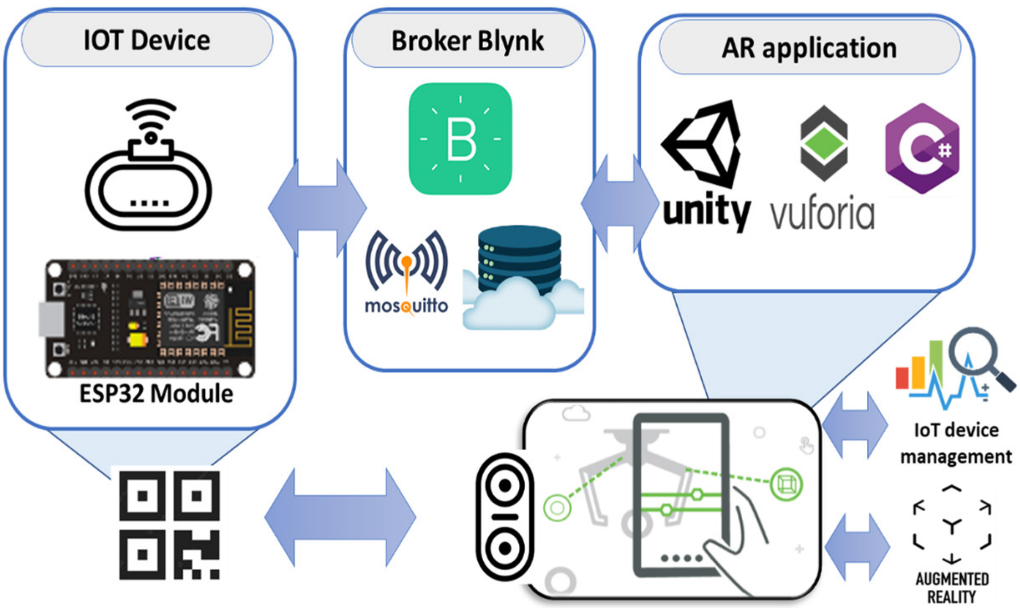

Fig. 2. Architecture of the proposed system

3.2 IoT system

The construction of the IoT system involves the use of environmental humidity and temperature sensors, along with motor-based actuator devices and luminous visual indicators. These devices, which facilitate communication and data collection, are managed by a program in the ESP32 module microcontroller. Communication is conducted through the MQTT protocol, allowing efficient data transfer (see Figure 3). The core infrastructure includes an IoT platform based on a Blynk service called MQTT Broker that stores, processes, manages, and visualizes data. The elements used are the following:

IoT devices:

- Environmental sensors: Based on a DHT22 sensor that acquires temperature and humidity data.
- Actuators: Perform an action in response to remote commands. In this case there is an SG90 servomotor and indicator lights based on LED diodes.
- ESP32 module: They manage the collection of sensor data and communication with other components.

Communication:

- MQTT protocol: Used for communication between the IoT device and the central infrastructure. In this case the PubSub-Client library is used.

Blynk IoT web platform:

- Its function is to store, process and manage the data received from the IoT device.

With the characteristics of the components described, the implementation of the IoT device was conducted as seen in Figure 4, where the components are integrated into an electronic board.

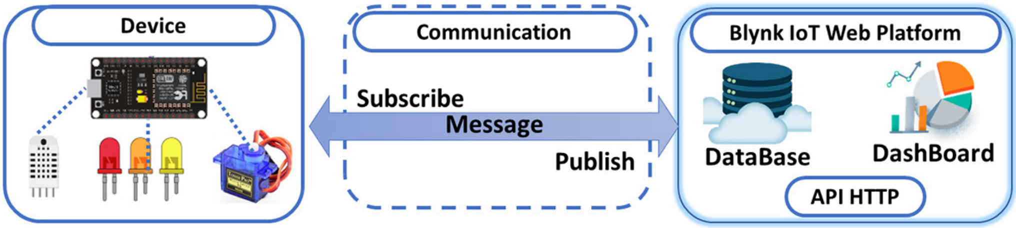

Fig. 3. IoT system components

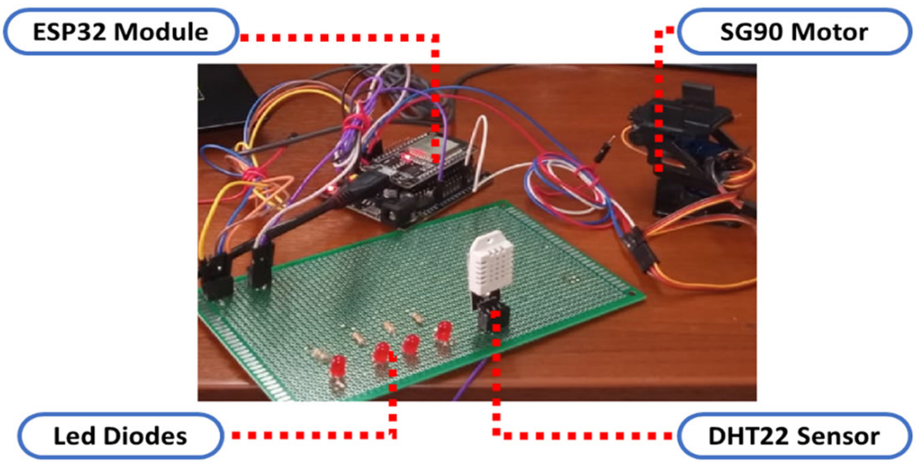

Fig. 4. IoT system implemented

3.3 Immersive interactive augmented reality interface

This section focuses on the development of an AR application that introduces an interactive dimension to the user experience. Unity software and an Android mobile or smart phone are used to allow users to view data from digital sensors and take control of actuators connected to IoT devices. In this context, AR and UI combine to create a powerful experience that gives users greater control and understanding of temperature, humidity, and actuator control via virtual buttons using a visual pattern marker, as shown in Figure 5.

Fig. 5. GUI components for AR application

The application development methodology involves the design of the AR display and controller. Then, marker tracking and detection functionalities are integrated, allowing virtual objects to be superimposed on the real world. The components of this stage are:

- AR software: Unity is used to develop AR applications that overlay digital information on the physical world.
- AR devices: The mobile device is used to provide the interface for users to see information overlayed on the real world.
- User interface (UI): Used to display sensor data and the status of IoT devices in real time through the AR interface.

Fig. 6. Implementation of AR application

3.4 System integration in a digital twin environment using REST API with C#

The use of DT in this context lies in the need to maintain a digital representation of sensor data and actuator control in real time for the IoT device, and despite the absence of 3D models, it allows the devices and their data to be continuously recorded and updated. Integrating a system into a DT environment using an HTTP REST API with C# leverages its advantages to enable contextual data visualization, real-time monitoring, interactive simulation, and predictive maintenance. In addition, a C# script for communication with the Blynk server's HTTP REST API is integrated into the AR application to send and receive data to its repository.

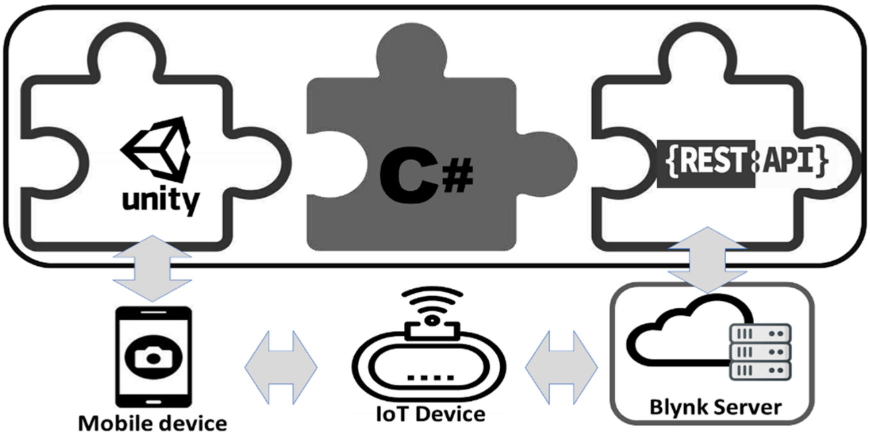

Fig. 7. Structure of the integration of the AR application with the IoT system in the context of DT

The implemented program consists of a C# script that connects to a web service via HTTP to obtain and send data. Its main functionalities are:

- The script starts by declaring input field variables to capture temperature (Temp) and humidity (Hum) data in the user interface. It also defines a ten second refresh interval for data collection and a virtual button used in Vuforia.
- In the Start() method, the Temp and Hum variables are initialized by searching for objects in the Unity scene. Additionally, an OnButtonPressed_on function is registered to run when the virtual button is pressed.
- The UpdateData method runs in a rolling update routine and calls the GetData_tem and GetData functions to make HTTP requests and obtain temperature and humidity data using the UnityWebRequest method.

In addition, the data delivered by sensors is represented by virtual components accessible from the MQTT Broker through MQTT requests and REST requests. These elements are show in Table 1.

Table 1. Components used for reading and control

Name	Virtual Pin	Type of Data	Widget Visual	Component	Pin Hardware ESP32
Ledrojo	V0	Integer	Switch	LED	26
Ledamarillo	V1	Integer	Switch	LED	27
Ledverde	V2	Integer	Switch	LED	14
Ledazul	V3	Integer	Switch	LED	12
Temperatura	V4	Double	Gauge	DHT22	15
Humedad	V5	Double	Gauge	DHT22	15
Automatico	V6	Integer	Switch	Servo Motor SG90	16
Integer V9	V9	Integer	Switch	Servo Motor SG90	16

The HTTP requests made from the C# script within Unity consist of making a GET request that is used to obtain temperature data that is authenticated on the Blynk platform by validating a token and entering virtual pins as a parameter to specify the source of specific data. Like the previous one, the data on the humidity variable is obtained. The URL includes the same access token and the v5 parameter, which refers to a specific Blynk channel. Finally, an update request is used to control the SG90 servomotor (refer to Table 2).

Table 2. REST API requests for updating virtual controls

Componentes	REST API Request
Temperatura	https://blynk.cloud/external/api/get?token=ihgjgjO0PnDQe5_x95&v4
Humedad	https://blynk.cloud/external/api/get?token=i2Tk5rljkljnDQe5_x95&v5
Control de Servomotor	https://blynk.cloud/external/api/update?token=i2Tk5rQe5_x95&v9=1

4 RESULTS AND DISCUSSION

The results presented in this section allow us to validate the fulfillment of the objective of the research project based on a descriptive methodology through the deployment of the prototype in a digital transformation demonstrator space. Communication between the physical device and the AR application within the context of DT was established efficiently, allowing data transmission in real time.

In addition, precision was achieved in the transmitted values by configuring the decimal values, both in the virtual variables of the Blynk platform and in the data processing conducted in the C# script for visualization in the AR application. The correct superposition of the digital and physical environments was also demonstrated, although a small displacement error was detected between both due to the lack of an adequate light source, and the system demonstrated its ability to fulfill tasks such as picking and placing viewing objects in an efficient way.

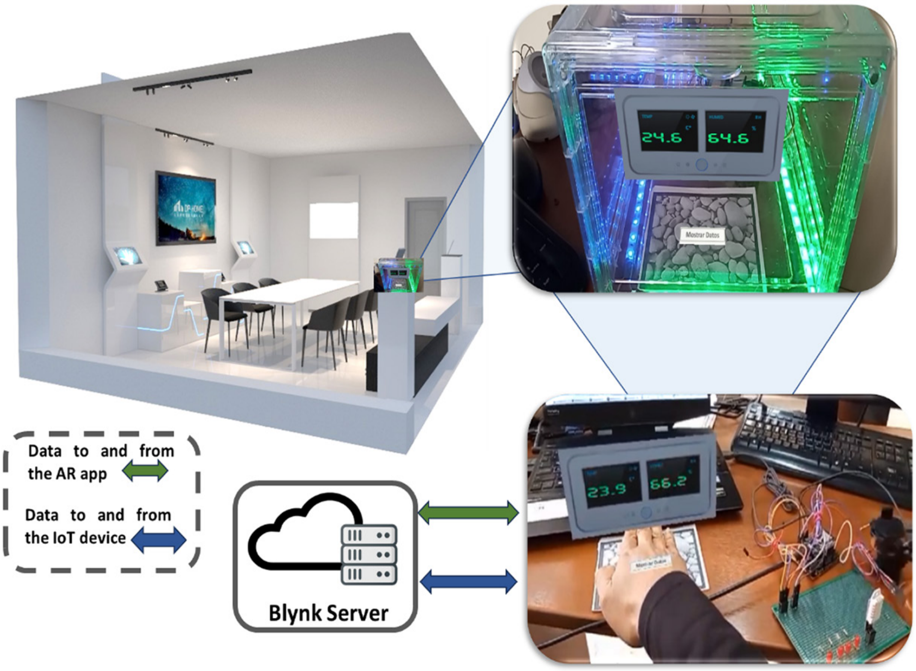

Fig. 8. AR app view showing real-time data visualization and motor control

Once the visualization of the GUI in the digital world is advanced, its position in the real world is obtained, where the user can begin the interaction process with the sensor or actuator elements [26]. Alternatively, the user could select the automatic mode through the AR GUI control panel to control the servo motor, by using their hand over the virtual button. The system was evaluated by people who validated the interaction with the virtual components for the first time using the application on a tablet with the Android system. An agreement was obtained from the participants regarding its usability without the need for prior knowledge or training.

5 CONCLUSIONS

In this study, AR technology is used, focusing on its integration with an IoT application within the DT paradigm. The strengthening of the CET INICTEL-UNI services for the digital transformation of Peru and their use in a demonstration space are used as a case study. The objective of initiating a proposal to contribute to eliminating the inertia of technological change by raising awareness and predicting its potential use to improve processes in Peru is met.

This system uses an AR application to capture the geometry and configuration of an environment and is complemented by a C# script to consume data through web requests to a remote MQTT broker. By using these tools, it is demonstrated that it is possible to create a DT of an intelligent environment that can be used for simulation, implementation, and synchronization between the real and virtual worlds.

The focus is on monitoring the state of sensors and actuators using digital representations, secure bidirectional data transmission, and 3D visualization. However, the analysis of the information collected will be addressed in future studies to generate an intelligent solution, which involves deeper investigations and the use of advanced AI and ML algorithms.

Although in some cases the approach to the marker was not adequate, its detection and generation of the AR interface were successful. In future work, AI-based algorithms and the spatial awareness capacity of the portable device that replaces the smartphone used in the digital model overlay will be explored.

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