Developing a web-based digital twin platform for robotic arm analysis

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***Abstract*—This article describes the creation of a system for creating web-based digital twins. The system has a 3D visual simulator, and this simulator runs directly in browser. It supports data visualization with dashboard and augmented reality. To validate the system, a robotic physical arm was built with LEGO. In this arm were placed sensors connected to a microcontroller. The microcontroller sends the data to a database on the web. Your digital counterpart was created in our simulator. The article presents the results of this simulation.**

***Index Terms*—digital twin, internet of things, augmented reality, robotic arm**

I. Introduction

The manufacturing process adopted by the industries essentially evolves over the years. Those sets of conditions that undoubtedly characterized an evolution in the way products could be produced are called the industrial revolution. Three of these revolutions have already been noticed throughout history. It is believed that the world is currently moving towards the 4th revolution. This revolution is linked to the creation of "intelligent objects", their ability to apply sensors to the environment and send us the data of their sensors [1]. This communication of intelligent objects with us takes place through wireless communication, whether through the Internet or a short-range transmitter, such as Bluetooth antennas. If several of these objects have a wireless connection to the Internet, they can exchange data between them forming the Internet of Things [2].

The ability to exchange data among things that operate on a factory assembly line would allow the now-intelligent equipment to collaborate in the manufacturing process and instead of being just passive agents. This collaboration of machines in the manufacturing process would be so disruptive that it was considered the birth of the so-called industry 4.0 [3].

The industry 4.0 does not come only with the use of Internet Systems of Things in an industry. Lasi et al. [4] argues it also involves changes in production, with the introduction of a flexible production system. For Weyer et al. [5], it occurs through the deployment of cyber-physical systems [6]. Cyber-physical systems are electrical and / or mechanical systems with increased computational power. The creation of cyber-physical systems occurs with the addition of embedded systems [7] in electrical and / or mechanical equipment, which previously did not have processing power and internal data storage [8].

According to Weyer et al. [14], the structure of industry 4.0 involves two other aspects besides the deployment of cyber-physical systems. These aspects are The Smart Product and the Augmented Operator. The Smart Product is based on the product description through metadata files, which would efficiently store lots of strategic information about the product [18]. The Augmented Operator involves the use of technologies that allow factory operators to quickly and dynamically view data from the manufacturing process to make decisions. The interfaces that can allow this visualization are constructed with Virtual Reality [21] and Augmented Reality [20].

Among these technologies that the advent of Industry 4.0 offers to the industries is the use of digitals twins. A digital twin is a digital (or in other words, virtual) representation of a real-world object [1]. This digital representation is made by the combination of technologies of sensing, internet of things [2], data analysis and virtual simulation environments.

An object that has sensors connected to the internet can send selected data about this object in real-time. This data goes to a server in the cloud and there it is stored in a database. The stored data can be used to assemble a history of the object's behavior. All this information can be used for very different purposes, like posterior visualization, inspections, or even the development of prediction models to simulate the behavior of the object under more general circumstances. This set of actions represents the functioning of a digital twin, which can be seen as a synchronized visualization of the data of an object [3].

The definition of digital twin was proposed by Grieves [4] which discusses its use of Product LifeCycle Management (PLM) [5]. The motivation for creating a digital twin is to reduce the production costs of a new product [6]. In addition, other stages of PLM, such as product maintenance, can also be optimized by the use of digital twins [7].

The concept of digital twin is recent but there are already some systems for building these products. Qi et al. [32] lists the platforms available on the market. All are proprietary solutions. Our proposal in this work is to present a solution that uses free and web-based software, called DTEAM

(Digital Twin Environment for Augmented Management). Our platform uses augmented reality and virtual reality for data visualization.

In section 2 a background of the area is made and some related works are listed. Section 3 presents our system. Section 4 discusses the results. In section 5, the conclusion of the work.

II. Related Works

A. Background

First, The technology of digital twins was employed first for aircraft design and manufacturing. NASA and the American Air Force used for manufacturing of new vehicles [8]. Tuegel et al [9] describe the use of digital twins as a way of predicting the performance of an aircraft during its useful life.

Luo et al. [25] developed a system for creating digital twins for CNC machines. The work presents an architecture that organizes the system in 3 layers: the physical layer, digital layer, and data model. This 3-layer architecture model serves as the basis for our work and its terminology is also used by other works that will be cited in this section.

The physical part of the twin has sensors that collect data. The data collected will only be useful when viewed, so it is possible to find different approaches for visualization, but the use of Dashboards [32] and Augmented Reality [19] are the most cited. Now that we talk about the basics of a system for digital twin, we can address some area jobs.

B. Digital Twin systems

Autiosalo [24] presents a study on the use of digital twins applied to industry. The proposed platform is used for research and teaching purposes, as well as ours. Visualization of sensor data is done with augmented reality glasses. Another application work in the industry presents the concept of proof of the development of a digital twin creation system [27]. The authors used a CAD tool to visualize the data.

In article [31], the authors discuss the use of digital twin in an industrial production line. The digital layer is used to simulate problems occurring in the physical layer so that they can be healed. The focus of this project is the simulation of problems, not the visualization of data. Another system presented by Schroeder et al. [26] is focused only on the specification of the data model since it uses the FIWARE platform [23] as the basis for the digital layer. In our proposal, we chose to create our own digital layer, as will be discussed below.

The work of [28] presents a modular platform for creating visualizations with augmented reality, as well as our proposal. They conduct a case study applied to the digital twin visualization on an industrial platform. In another paper Schroeder et al. [29] discuss the creation of digital twin visualization system with augmented reality. The proposed system is based on the use of web services and uses a client-server architecture. This proposal to use web services was also followed in our project.

III. The system development

Our system is composed of three layers as presented in Figure 1 (Physical, Data end Digital). The Physical Layer is composed of the robots, the microcontrollers, sensors, devices, and physical transmissions connections. The sensors are mounted in microcontrollers attached to the robots. This is the minimal physical scenario to support the internet of things communication environment.

The Data Layers represent the metadata exchanged between the Physical Layer end the Digital Layer. It is made up of databases and metadata protocols. The metadata protocol used in our system is MQTT [33]. When the microcontrollers are initialized they connect to the WIFI and to the Broker MQTT.

Fig. 1. System architecture in 3 layers: Physical Layer (Left), Data Layer (Middle) and Digital LayerRight).

Via the Digital Layer is possible to send commands to the robot arm, control shoulders, elbows or the end effectors, those commands are send using MQTT protocol so multiple micro-controllers can send and receive information dynamically.

The Digital Layer 3D visualization is created with Three.js, with a box model of the robot, as a placeholder. The information acquired from the sensor can be visualized by colors on the model. The Digital Layer also has a dashboard version with charts to allow a historic of the data and a real time visualization. The dashboard is created with Thinkspeak web service. The dashboard view of the systeam can be seen on Figure 2.

A. The system execution flow

The system assimilate states of its components, so if a command is sent to a motor it will expect a response from the microcontroller telling if it is on or not. The response is the signal from two rotary encoders built-in on the robot motors. They send two values to the microcontrollers, a 0 or 1. The combination of 0s and 1s tell if the motor is running

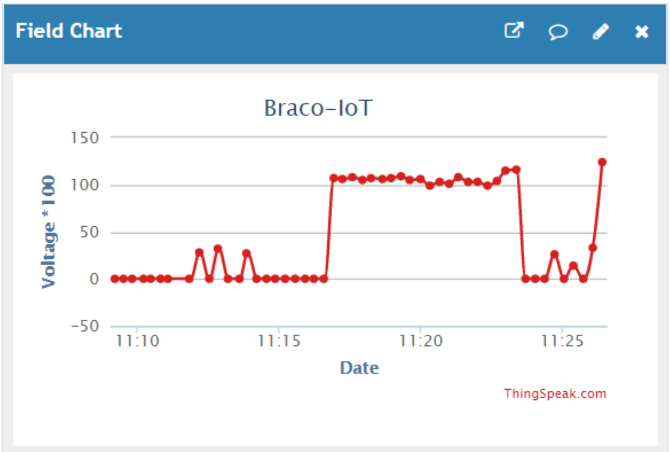

Fig. 2. System dashboard created with Thingspeak web service.

forward, backwards or not moving at all. So with that feedback the microcontroller sends a string to the Data Layer telling which direction is the motor running and moves the 3D model accordingly. The Figure 3 shows the 3D visualization of the Digital Layer.

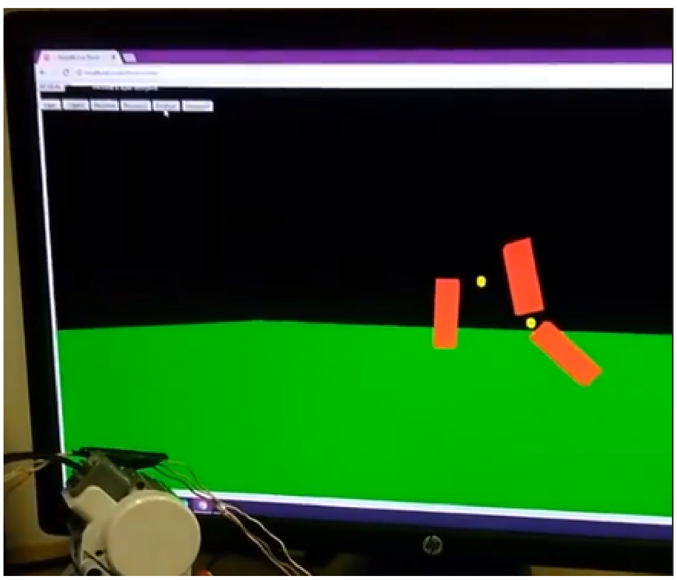

Fig. 3. The visualization of the 3D simulation of a robotic arm with 2 joints and 3 axis.

The communication between the Physical and the Digital Layer occurs in two ways. So, at the same time the voltage meter, built with two 1k Ohms to drop the voltage below 3.3, sends to the Data Layer a value that corresponds to what voltage the motors are using, if the voltage use drops it means that the motor is under load, which is shown in the 3D simulation.

The method used for load measurement is based on the production of CEMF (Counter-Electromotive Force) during motor movement. The system current is calculated by the difference between the applied voltage and CEMF, so if the rotation is high, the final voltage is less than the applied voltage and the current decreases, if load is applied, the rotation is low, the final voltage is close to the applied voltage value and the current increases, this current increase causes a voltage drop in the internal resistance of the power supply.

VS VCEMF = I*R (1)

Where Vs is the Voltage Supply, Vcemf is the CEMF produced, I is the current and R is the resistance.

The system also has an interface for displaying data with augmented reality. The augmented reality model used in this system is based on fiducial markers [34], because its low cost and robustness. This augmented reality service was created with the Unity gaming engine [35] and Vuforia augmented reality library [36].

IV. Results

A. Material and methods

In order to validate our system we develop a Physical Layer with a robot arm and its Digital Twin. The robot arm was built of LEGO because it is easily assembly and disassembly, scalability, and the possibility of creating an educational kit about Industry 4.0. It has few parts, four NXT motors, two as the shoulder, one as the elbow, and the last one as the end effector, LEGO Technic beams and gears for reduction between the motors,.The arm is showed in the Figure 4.

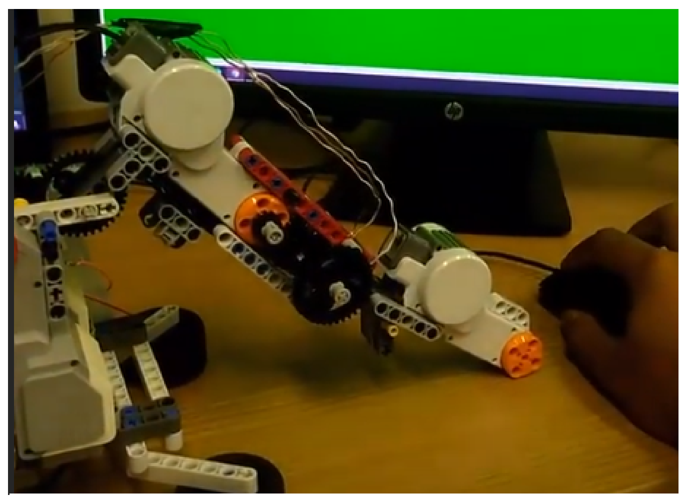

Fig. 4. A LEGO robot arm used to validate the system.

The circuit of the sensors was composed of two NODEMCU ESP8266, two ESP Motor Shields, rotary encoders(built-in on the motors), buttons as end stoppers, and a PCF 8591 to allow analog to digital conversion, voltage dividers as sensors to read the voltage of the motors.

B. Experiments

To validate the system a experiment was performed where a load is applied to the physical arm. When receiving this load the sensors of the arm should send a signal for this load to be stored in the Data Layer. The Data Layer should send a message to the Digital Layer for the load to be represented in the simulation environment. The visual result in the simulation should be a change in the color of the axis affected by the load. The result of this test can be seen in Figure 5. It's not clear in the picture, but the engine is spinning at low speed.

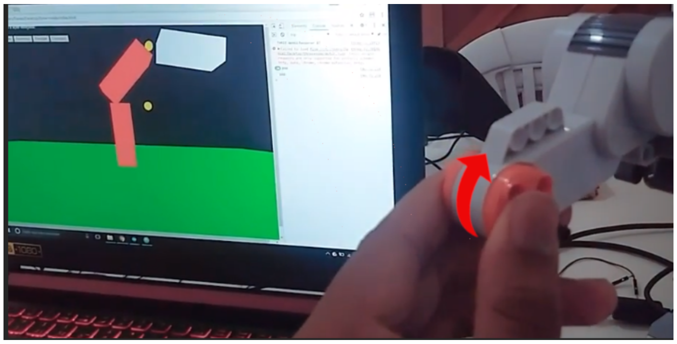

Fig. 5. Validation test of the digital twin. When the physical arm receive a load its digital twin changes. The digital arm was complete red in the begin, but become white when receiving the load.

In another experiment, a test was performed with the augmented reality module. In this test, a mobile application recognizes a fiducial marker suitable for AR. The marker used was printed on a sheet of paper. When recognizing the marker the application draws on it an interface with control buttons. The buttons allow you to switch on the arm, turn off the arm or change the direction of arm rotation. The interface still displays a rotating square that illustrates the current direction of rotation. The environment of the second experiment can be seen in Figure 6.

In this second experiment the application is running on a mobile device. In this case, it is the mobile device that sends the signals to the Data Layer. This illustrates that our architecture supports different devices integrated to the system, where all these devices are able to send control signals to the Data Layer.

The second experiment also demonstrates that the mobile device is able to receive messages from the Data Layer. When the interface is drawn on the device screen, it receives the current direction of arm rotation. This information is represented graphically in the interface. Whenever the sect of rotation changes its graphical representation is changed at the interface of the device.

V. Conclusion

The idea of merging all these concepts allows a constant and dynamic data collection, that is, the system can read the state of its elements and assimilate the results several times per second. In order to have a perspective on how this system allows greater and easier control of a production line, it is necessary to have the dimension of the quantity of data and its importance. For example, in one of the Fiat production lines there is a module that has 18 robotic arms that assemble up to 6 different chassis types, each robotic arm has 6 axes, which means that there are 6 motors in the arms of each engine is possible we can analyze the position of each part of the

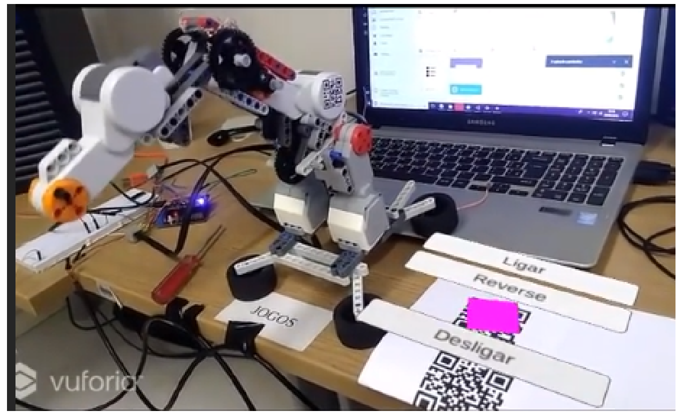

Fig. 6. Augmented reality application to robot arm control.

arm, then we have angles, velocities and vectors indicating movement, that is, for only one arm we have 42 data being analyzed simultaneously, which are crucial data in order to have full information of what is happening in each arm.

This model provides a "omniscience" on the whole production process, each element of the line, and each component of the elements, integrating all this into a virtual simulation creates a more friendly platform for data analysis. Where the responsible by the maintenance does not have to be in the factory analyzing one robotic arm at a time, it does not have to disassemble a whole equipment to discover an error. It means that the cost and the time of equipment maintenance fall to advantageous margins for industries.

With this data we can analyze if the robot is doing something wrong or if there is a fault, for example, one of these arms is responsible for lifting a chassis of 1.5 Tons, when analyzing the current consumed in each motor we can know the stress exerted, and when we apply the geometry, the distance and position between them, we are able to calculate the torque applied to each joint of the robot, so we know the data about the task that the arm executes, from this a mean of these values are calculated for the calculations, if the values start to change frequently the system identifies that the equipment is worn and needs maintenance.

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