Visualising the Digital Twin using Web Services and Augmented Reality

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***Abstract*—As the number of network connected devices in an industrial system increases, the management and handling of all the information generated become a challenge. In this work we explore concepts of Cyber-Physical System model the virtual part of industrial devices (sensor, machines, CLPs) using the Digital Twin concept and propose an architecture based on web services for accessing their data. We present a case study where an Augmented Reality system access the Twin Model data via web services and display real-time information to the user. Moreover, we present a review of how the involved concepts, which have a strong computational background, relate to industrial applications and how they can expand the possibility of services and business models.**

I. Introduction

We are facing the fourth industrial revolution or the so called Industry 4.0 [1] not only in the European community.

In this context, field devices, machines, plants, factories and even individual products will increasingly be connected to a network (e.g. the Internet or a private factory network). This will allow them to become searchable, explorable, and analyzable via the network, leading to potentially new types of services and business models in the value chain. However, this also leads to a significant increase of available online objects, making it difficult to manage all data sources both from a computer system point of view as well as from a human-interaction point of view.

On the computational side, Cyber Physical Systems (CPS) have been proposed as a key concept of Industry 4.0 architectures. A CPS can be described as a set of physical devices, objects and equipments that interact with a virtual cyberspace through a communication network. The cyber model of each physical entity can be seen as a digital representation of the real entity, thus is sometimes called “Digital Twin”[2][3]. The Digital Twin can monitor and control the physical entity, while the physical entity can send data to update its virtual model.

On the human-interaction side, Augmented Reality (AR) systems are becoming an interesting and viable solution. AR is an area of Virtual Reality (VR) that combines real and virtual visual components in the same scene to improve the human-computer interaction. Through the use of AR devices such as transparent glasses, tablets or smartphones, it is possible to view the real environment as a background, while being guided by virtual information overlaid in an interface in real-time [4].

This paper focuses on an architecture based on Cyber Physical Systems (CPS) for accessing their data with the use of augmented reality for the Human Machine Interface. The data is retrieved from different data repositories using web services, which implement the Digital Twin concept. We propose a concept to visualize the product data using augmented reality.

This article is structured as follows: the following section explains the theoretical foundation and related work. In Section 3 we present the key enabling technologies for implementing the concept of an architecture, that is proposed in section 4. In section 5, a case study is described. Finally, in the last section conclusions are drawn and future work directions are signaled.

II. Theoretical Foundation and Related Work

This section presents a state-of-the-art review of related work using CPS and Digital twin These ideas are the core for our work.

A. Cyber-Physical Systems (CPS)

CPSs have the ability to transform the way human-to-human, human-to-object, and object-to-object interactions take place in the physical and virtual worlds. The increasing pervasiveness of Wireless Sensor Networking (WSN) technologies in many applications makes them an important component of emerging CPS designs.

A CPS is the integration of abstract computations and physical processes [5] [6], where sensors, actuators, and embedded devices are networked to sense, monitor, and control the physical world. In contrast to traditional embedded systems, the CPS is a network of interacting appliances with physical inputs and outputs instead of standalone devices. A typical CPS application is to connect appliances embedded with sensor nodes (which are responsible for information collection from the physical world as the source of CPS inputs) to

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some real-time decision making systems (which represents the virtual world).

Fig. 1 illustrates the architecture of a CPS which is mainly composed of one physical layer and one virtual layer. At the physical layer, sensors and actuators are responsible for collecting information and acting into the physical world, respectively. In addition, the different types of collected information by sensors are also converted from the analog format into the digital format, and then sent to the virtual layer (data stream). In the virtual layer, the data management system keeps the historical data in a database and send to the data analytics system. Upon receipt of the inputs, the decision making system executes the abstract computations to analyze the collected data and then relays its decision to the actuators in the physical world by a sequence of control processes.

The application of CPS concepts to industrial applications has been discussed in several papers. For instance, [7] presents an unified 5-level architecture as a guideline for implementation of CPS. The authors argue that it is essential to clearly define the structure and methodology of CPS as guidelines for its implementation in industry. This work, also gives an initial idea of the digital twin being the cyber part of a Cyber Physical System. Also in [8], the authors discuss about the importance of the Digital Twin for the future of manufacturing. They say that Digital Twin enables all models and all data available in a consistent way for the knowledge on the current state of the production system in the context of Industry 4.0 and CPS.

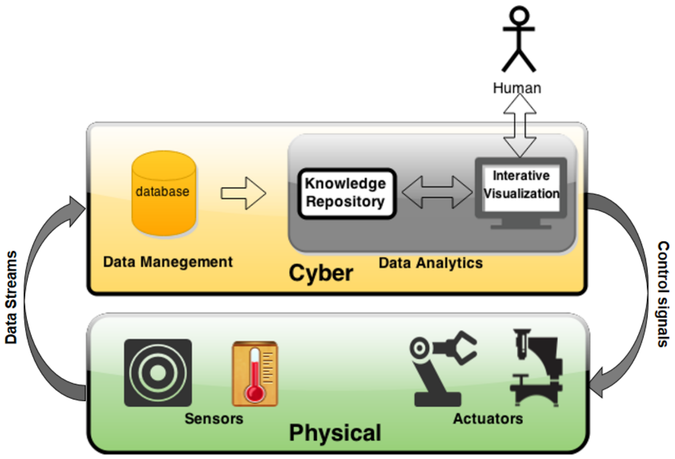

Fig. 1. Architecture for CPSs integrations.

B. Digital twin

The Digital twin is a virtual representation of the physical product, a digital shadow that contains all the information and knowledge of it. It is connected with the physical part in some way, allowing data transfer from the physical to the cyber part. It is defined as a distributed and decentralized approach to manage product information at product item level along its lifecycle [9].

The digital twin is directly linked to the concept of Product Lifecycle Management (PLM) systems [10]. PLM consolidates diverse business activities that create, modify and use data to support all phases of a products lifecycle from “begin-of-life” (design, production), “middle-of-life” (use, maintenance), and “end-of-life” (recycling, disposal).

A digital twin includes both static and dynamic information. The static information can be: geometrical dimensions, bill of materials, processes, etc. The dynamic information is the one that changes with time along the product lifecycle.

A digital twin can have intelligence. For example, an intelligent product can retrieve information about itself and is capable of participating or making decisions about its own future [11]. As pointed out In [12] an intelligent product presents following characteristics:

- Requires a global unique identification;
- Is capable of communicating with its environment
- Can retrieve and store data about itself
- Is capable of participating in or making decisions relevant to its own destiny

It is not necessary to have all these characteristics for a digital twin, since all these are related to intelligent product. However, some of these characteristics are relevant for the management of the digital twin.Having this in consideration, the most relevant topics for the creation of the digital twin can be summarized as follows [3]:

- **Identification**: the product needs a global identification to link each physical product to its digital representations. Some technologies that can be used for this are: RFID tags and the Electronic Product Code (EPC) [13]. It provides a unique identity for every physical object anywhere in the world and for its whole lifecycle.
- **Data management**: product data and information are created and evolve along the three stages of the product lifecycle: BOL, MOL and EOL. The size of the data stored along these stages can achieve big proportions. And, with this comes up the problem of Big Data management and analytics for storing only the significant data.
- **Product models**: different types of product models are created during the different phases of product lifecycle. Some of these models are: system models, functional models, 3D geometric models, multiphysics models, manufacturing models, and usage models. Such models, sometimes, are interoperable among each other and this is a critical problem since. The models should have a way of “speaking” the same language.
- **Human Computer Interface**: having so much information to handle in different data repositories may cause a problem for retrieving and showing the necessary information for the right user. The digital twin can provide information to all kind of users and to all stakeholders involved in his life. So, it is necessary to develop Human Computer Interfaces (HCI) for the digital twin.
- **Communication**: it is necessary to have a communication path between the place where the data are stored and the HCI. The digital twin can store his information in

different databases. However, with the new technologies for the Internet of Things, it is necessary to have a way to retrieve information from these databases from any place at any time.

III. Key Enabling Technologies

In this section, we present the key enabling technologies for implementing an augmented reality systems in which different users can access the information stored in the digital twin. The idea is to have different databases, located in different places. With the use of web services, the AR systems can query the information stored in these repositories. Here, we explain what are AR Systems, how they work, as well as what are web services.

A. Augmented Reality Technologies (AR)

Augmented reality (AR) is a technique for superimposing digital content onto the real world, using either optical or video see through head-mounted displays (HMDs) or handheld viewers[4]. For the latter, mobile devices such as smartphones and tablets have proven to be popular and highly versatile, literally putting AR technology into a persons hand. The AR techniques have been applied in many different areas such as education [14], design [15], manufacturing [16][17][18], navigation [19], entertainment [20], and medical diagnostics [21].

The pervasive and persistent presence of next-generation computing and communication devices in the form of smartphones and tablets have a transformative impact on AR sytems. In particular Mobile Augmented Reality, also referred to as MAR, has gained popularity in many research domains as well as the commercial market. Compared with traditional AR platforms, MAR systems tend to be lighter and more portable.

Fig. 2 describes the main tasks in an augmented reality application. The first one, is searching the marker inside the camera flow. If the marker is recognized in the scene, the virtual object associated with this marker, is put over the position of the marker by adjusting the virtual model with the marker position. Then, the virtual model is rendered in the video flow with the environment. In case the marker is not recognized, the AR application keeps searching for a marker in the environment.

The use of Augmented Reality in industry is mainly related to maintenance. In [22], an AR e-maintenance platform design is presented. The aim was to help a technician during his intervention. The work was focused on synchronous and remote collaboration between technicians and experts to complete maintenance and repair tasks by giving augmented information on the users field of view.

[23] also presents the use of AR in maintenance trying to extract the user skill for using in Intelligent Maintenance Systems. And, another work that involves using AR systems to visualize data in Cyber Physical Systems, can be seen in [24].

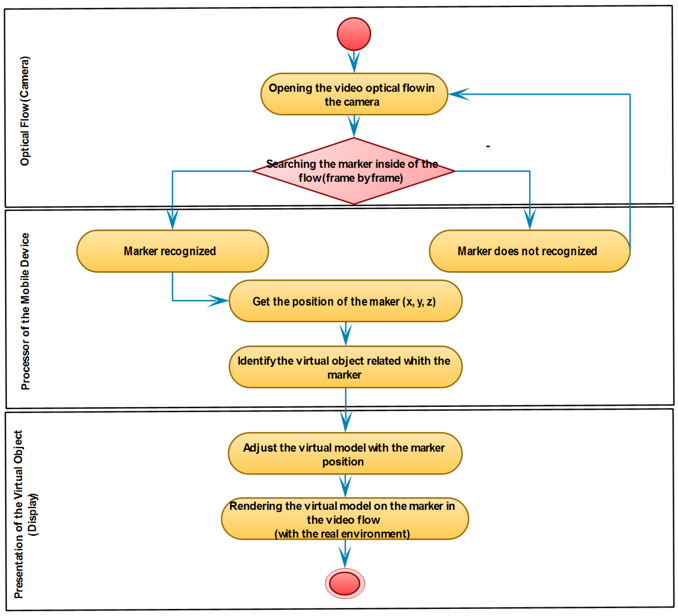

Fig. 2. Architecture layer of Augmented Reality.

B. Web Services

Web services are defined as modular units of application logic that provide functionality for other applications over the network [25]. It acts as an abstraction layer, separating the programming details (such as programming language and platform) of how the application code is invoked [26]. Thus, programs in different languages and platforms can communicate through the use of this technology.

This kind of technology have been used in some works in industrial applications, as described in [27], motivated by the fact that a Web service can be seen as a software system designed to support interoperable machine-to-machine interaction over a network. Many industries companies use multiple software systems for management and them need to exchange data with each other. A Web service is a method of communication that allows two software systems to exchange this data over the internet.

The two main protocols on Web services are Simple Object Access Protocol (SOAP) and Representational State Transfer (REST).

1) SOAP: SOAP-based architecture has its communication of Extensible Markup Language (XML)-encoded messages over Hypertext Transfer Protocol (HTTP). SOAP service sets are defined in Web Service Definition Language (WSDL) files which are XML files standardized according a W3C-specified grammar [28].

2) RESTful: The REST was introduced as an architectural style for distributed scalable systems and large-scale systems. Given that the great majority of RESTful Web services are not described using the WSDL description, it's not possible to reuse existing clients that require this description. REST is based on four architectural principles [29]:

i. Resource identification through URI: exposes resources which identify the targets for interaction with its clients.

ii. Uniform interface: resources can be manipulated using four operations: PUT (create), GET (read), POST (update), DELETE (delete).
iii. Self-descriptive messages: the resources can be accessed in a variety of formats (e.g., HTML, XML, plain text, etc).
iv. Stateful interactions with hyperlinks. The interaction with a resource is stateless.

IV. Proposed Architecture

In Fig. 1 we showed that a CPS is composed by a data collection system (from sensors); a data management system; a decision making system and an interative visualization system for interacting with the human. In this context, the goal of this architecture is how to visualize the physical data in the context of a cyber physical system using Augmented Reality (AR) systems. The architecture of the proposed system is illustrated in Fig. 3. This architecture is divided into five layers: devices, user interfaces, web services, queries and data repositories.

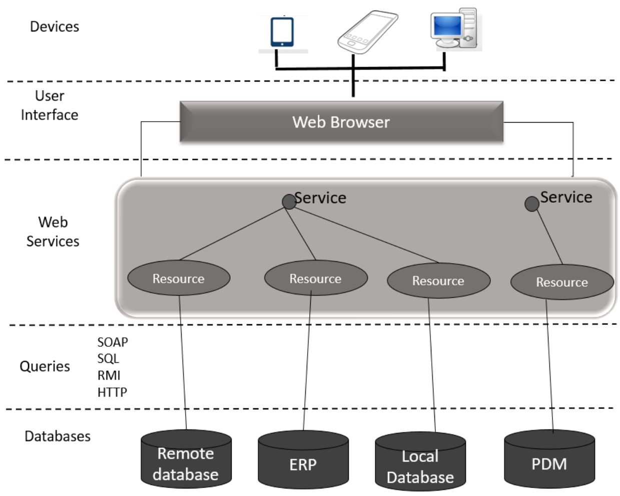

Fig. 3. Concept of the architecture for digital twin data management based on web services

A. Device Layer

The first layer is composed by the devices. They can be computers, tablets, mobile devices, etc. The device runs the visualization systems, in this case the AR system. The user operates the devices as a client in this architecture.

B. User Interface Layer

The users can operate the devices via the user interface, that can be a augmented reality interface. The user interface accesses the web service using a browser.

C. Web Services Layer

The web service used was the RESTful web service. It has services and each service can have several resources. Each service can be considered as an individual task and can be addressed by a HTTP call. In order to retrieve all information related to the request made by the client, the HTTP calls the service and it collects the requested information provided by the involved resources. The response from server is considered as the representation of the resources. This representation can be generated from one resource or more number of resources.

D. Query Layer

The resources build queries as a way to retrieve data from the database. The protocol type of each query depends on the software used by the data management systems. Possible protocol types are SOAP, SQL (Structured Query Language), RMI (Remote Method Invocation), HTTP and others.

E. Data repository Layer

Resources retrieve data from the database systems. The advantage of using a RESTful web service is, independent of the type and structure of data management system, the data is accessible in the same way.

The benefit of this idea using web services, is the access to data stored in different data management systems using a web browser. This enables the retrieval of manufacturing data and the use of mobile devices.

V. Case Study

A case study is presented to illustrate the proposed approach introduced in the last sections. We implemented the use of Web Services to retrieve information from a supervisory system (used as a data repository) together with an AR system (client) to visualize the data. The AR System provides a user interface for the device.

The example is used for visualizing the extraction and initial processing of oil and gas in an offshore oil platform. This is a CPS process example. Basically, the process has three stages as represented in Fig. 4. In this figure, we have the representation of three tanks for storing gas, oil and water. These tanks, are probably controlled by supervisory system that control the level of storage. But if we are allowed to have a digital twin for each tank, we may have access to additional tank information. For example, we can see the data when the tank was built, information like the size and capacity of the tank, manufacturing data and, real time data collected by sensors in each tank. In this case study, we selected the real time data from the sensors to be showed: the level of gas, oil and water data are being displayed in the augmented reality interface.

The Web services and web interfaces used in this work were implemented in PHP and work together with a Apache[1] server. By the time the data is updated in the supervisory system, the variables are updated in the Digital Twinś database and in the web interface, allowing this data to be accessed over the network by a web browser. Fig. 5 illustrate the web interface used in the architecture. These interfaces also implement other features, such as, generating markers for the identification of the plant equipment.

[1] Apache: http://httpd.apache.org/

Fig. 6 illustrate the UML sequence diagram for the case study. The AR System (client) requests data from the web server with an HTTP GET request, for example, to the resource. The web server retrieves the data from a data repository, in this case, the supervisory system, and packages it into a convenient representation for the client. The data is returned in the form of a document. The documents are commonly text strings containing JSON or XML encoded objects. The client manipulates the data representation.

In the augmented reality application, pictures previously prepared and printed are placed on real environment so as to serve as a basis for recognition and positioning of virtual objects.

During the execution of the application, the real images are seen through the optical flow, frame by frame. Once found the marker positions in the image of the frames, the virtual elements are inserted over the markers. So, the video stream is displayed on the mobile device screen with virtual elements inserted into it.

All graphics processing is performed directly in the device. The only requirement to display the values captured by the supervisory is the connection with Internet or local network. Features such as the recognition of QRCode's tags have been implemented so to allow the identification of any equipment and display information on different virtual models.

For the implementation of AR application we have used the Unity Integrated Development Environment (IDE) and the Vuforia SDK (Software Development Kit) using the C programming language. The SDK Vuforia supports a lot of markers that can be generated and customized from the site developer. The result of applying the implementation can be seem in Fig. 7. The figure shows a 3D ship prepared to illustrate the context where the tanks are inserted. Above the ship, we can see the level of oil, gas and water in real-time (the data are retrieved from the supervisory system as explained earlier).

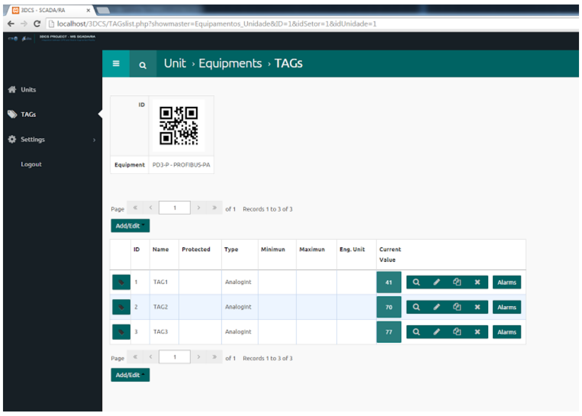

Fig. 5. Web Interface used in the proposed system to capture the gas, oil and water levels.

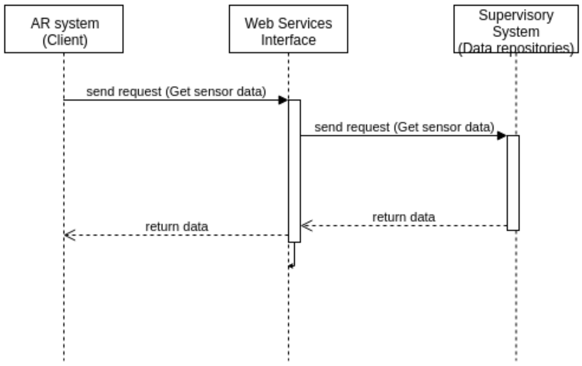

Fig. 6. UML sequence diagram for retriveing data from a supervisory system using web services.

VI. Conclusions and Further Work

In this work, we presented the concept of the Digital Twin, in the context of the Cyber Physical System and the Industry 4.0. The Digital Twin is a counter part of the physical device, machine or product in a CPS. It has the information related to the whole lifecycle of a product.

However, the focus here was to show how to retrieve data from the digital twin and propose the use of a augmented reality system as a user interface to visualize the data.

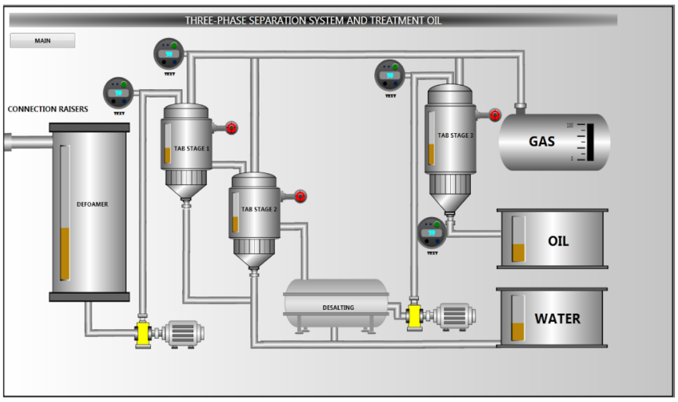

Fig. 4. Representation of the three phase separation and oil treatment.

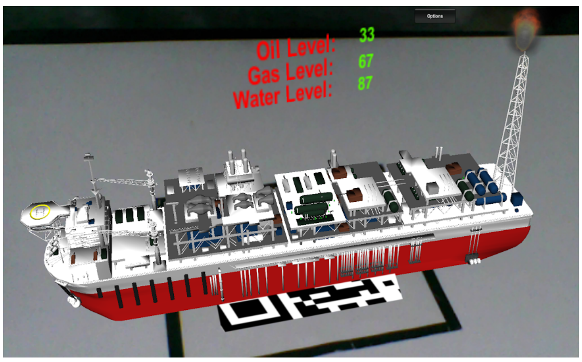

Fig. 7. Print screen of the augmented reality application showing the values tagged in the supervisory system.

A proposed architecture was presented with the aim to manage the data from the digital twin, using web services, to distribute the data in other systems like an Augmented Reality System. The case study used was a supervisory system as a data repository, web services and the Internet to access the real time data from the supervisory. The study case, illustrated how to get data from the Digital Twin of a tank and how to show this using a AR system.

The architecture using web services can enable users to easily access product, simulation and manufacturing data of a Digital Twin, via a web browser. It is independent of any device and enable the data to be visualized on portable computer and devices.

In future works, we intend to implement other data repositories, which will store and serve all information related to the digital twin. Also, we need to research how to collected the data, and build models for the data as well. But, the goals of this paper were achieved: present the concept of Digital Twin; access the Digital Twin's data from different repositories using Web Services and, present a study case using Augmented reality for Digitl Twin's data visualization

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