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Towards improving the future of manufacturing through digital twin and augmented reality technologies

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Abstract

We are on the cusp of a technological revolution that will fundamentally change our relationships to others and the way we live and work. These changes, in their importance, scope, and complexity, is different than what humanity has known until now. We do not yet know what will happen, but one thing is certain: our response must be comprehensive and it must involve all stakeholders at the global level: the public sector, the private sector, the academic world and civil society. Applications for the industrial sector are already numerous: predictive maintenance, improved decision-making in real time, anticipation of stocks according to the progress of production, etc. So many improvements that optimize the production tools every day a little more, and point to possibilities for the future of Industry 4.0, the crossroads of an interconnected global world. This work comes to contribute as a part of this industrial evolution(Usine 4.0). In this paper we introduce a part of a collaboration between industry and research area in order to develop a DT and AR industrial solution as a part of a predictive maintenance framework. In this context, we elaborate a proof-of-concept that was developed in special industrial application.

Keywords: Digital Twin; Augmented Reality; Predictive Maintenance; Industry 4.0; Automation; Evaluation.

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1. Introduction

Today, the complex nature of architecture, engineering and industrial construction increasingly enhances the need for the use of new advanced technologies. In order to improve their construction and industrialization projects processes as well as the advanced visualization of their services, industries are moving towards the adoption of advanced technologies such as Digital Twin (DT) and Augmented Reality (AR). Those are both a part of top 10 strategic technologies in industry 4.0. Thus, the importance to combine these new technologies through the development of new methods, tools and techniques that can improve the future of manufacturing.
The DT is one of the main concepts associated with the Industry 4.0 wave. This term is increasingly used as a new trend in industry and research. However, the literature does not provide a unique definition of this concept[28].

Digital technologies increase the possibilities of communication, exchange and cooperation: between people, people and machines, and even between the machines or industrial objects themselves. With the aim of improving its processes and the performance of its operators, the manufacturing of future invests in new modes of technologies as DT and AR .
Relying on reality by embedding virtual 3D elements, AR technology allows integrating precisely the virtual (what we have to do) with reality (what exists and what we see). In other words, it enable the users to visualize and interact with 3D objects, in the real environment, more easily than they can through a simulation or a computer screen [17].
With the emergence of the future industry' concepts, both technologies gradually invest industrial companies for many reasons. First, They allow improving business processes regarding for examples; operational time, dynamic and contextual help, real-time traceability, etc. Further, these technologies reconfigure the role of the professionals, by renewing and enriching their method of work. In addition, they enable manufacturers to benefit from the remote assistance of an expert, to reduce the hardness of the industrial work and help them to achieve their goals. That is why their applications became today more and more significant in the industrial environment (such as in maintenance, assembly, equipment control, etc.).

In this paper, we introduce a part of a collaboration between industry and research area in order to develop a DT and AR industrial solution as a part of a predictive maintenance framework. In next section (section 2), we introduce the context and the motivation of this contribution. In section3, we resume a part of studies that were developed in industrial context. in section 4, we elaborate a proof-of-concept that was developed in special industrial application.

2. Motivation

DT and AR bring new predictive maintenance solutions for industrial partner. This strategies lead to establish an alternative of actual industrial preventive maintenance solution which is the predictive maintenance. This paper is a preliminary contribution of this solution development. The purpose is to anticipate a breakdown, reduce machine downtimes and prolonging the life-cycle of products... These are the promises of predictive maintenance. This approach consists of collecting and analysing the data of industrial process, its temperature and its vibrations ... Then, set up an alert system to prevent a breakdown by intervening before this happened. Predictive maintenance goes further to improving both curative and preventative maintenance, which consists of repairing the breakdown once, and the preventive, which consists of planning maintenance interventions based on average usage. The predictive allows relying on the actual use of equipment to optimize maintenance operations, with cost reduction at the key. Chemistry was one of the first sectors to seize it. The method is being democratized today with the advent of the industrial internet. But setting up a predictive maintenance can be complex. Which data to choose? How many? Should we abandon preventive maintenance?. A variety of questions we are frequently asked while this concept is in his beginning and remains without a clear definition. It is therefore important that this new technologies are placed within a solidly defined framework. *What can be done to improve predictive maintenance ? What contribution bring the DT and AR in industrial processing new model ? How far is technological innovation the key to success?*

3. State of scientific knowledge

3.1. Digital Twin in Industry 4.0

The design of a virtual digital equivalent to a physical product or digital twin (DT) was introduced in 2002 by Dr. Grieves of the University of Michigan under the concept of Product Lifecycle Management (PLM) [9][20]. When he developed his definition, the practical application of the technologies of Internet of Things (IoT) was in its infancy, and so the definition remained academic. It took a few years for new technologies to be developed and we must wait years before offering an industrial definition. From 2015, different definitions were associated to DT in order to enlarge its contribution and to exhibit the importance of this concept in different industrial area, DT gets an extended definition in the context of Industry 4.0 and the Industrial Internet of Things (IIoT)[23][27][5].

Grieves describes the DT as a mirroring (or as a twin) of what exists in the real world and what exists in the virtual world. It contains all the information of the physical system. It is simply a representation of all disciplines and not only mechanical or geometrical part, but also an electronic representation, cabling, software, micro software, etc. not just the CAD model. The DT was born in the aerospace field and has only recently been adopted in industrial contexts as an example the "Iron Bird" which is a test bench intended mainly to simulate a virtual air-plane model[6][4] [14] and different other example of the emergence of DT is in NASA's new technology [8][26][24].

However, research that describes the DT in the production industry is still in the early stages. In 2015, with the work of [23], the definition of DT included the generic word "product", paving the way for the use of such concept in other areas rather than just aerospace sector, though their work was still inserted in the research on aircraft structures. Initial work in other sectors appeared before. In fact, in parallel with research in the aerospace field, the first research work on DT in the industrial sector was launched in 2013 by Lee et al.. In particular, [13] presents it as the virtual equivalent of production resources, not just the product, laying the ground for strategic debate on the role of DT in advanced industrial environments, such as Industry 4.0 consider it with its core technologies, big data analytics and cloud platforms. cloud forms. This debate continues today, and the work of Negri et al. [20] is inserted in this feed.

Indeed, [20] presents a systematic review on the DT concept. It introduces 16 definitions of DT in the literature developed between 2012-2016, the objective of this study is to determine a unique and relevant definition for DT in the industrial sector while studying research in various sectors and contexts. This study provides a better understanding of the proposed definitions of DT in the literature and assists in identifying the role of DT in Industry 4.0. According to this study, the DT is conceived as the virtual equivalent of a physical system whose objective is to simulate a process for various purposes, while ensuring real-time synchronization of real data, such synchronization is possible thanks to industry-proven 4.0 technologies and hence the DT is deeply tied to the real system [28].

3.2. Augmented reality in industrial context

Although the first appearances of the concept of AR have acted for more than twenty years, this technology has only made a significant evolution in the industrial environment recently, thanks to the miniaturization of electronic components, the increase in computing power, the autonomy of computers, and the widespread adoption of smartphones and other hand held devices [10][22].

In 1994, Milgram et al [18] have defined augmented reality, on one side, as a technology able "to increase the operator's natural feedback with virtual clues". On the other side as "the form of virtual reality where the participant's head-worn display is transparent". These definitions have been confirmed by Azuma in 1997 [3] who indicated that ARallows the user to see the real world with a superposition of virtual objects. He defines AR as a system "in which 3D virtual objects are integrated into a 3D real environment in real time" [3][22]. Johnson (2011) has proposed another definition, which indicated that AR is characterized by adding computer-generated context information layer into the real world, which leads to enhanced reality [12]. As other definitions, this one has also based on Azuma definition that can be considered as the most adopted one based on three basic criteria. Those are (1) the combination of the real environment with the virtual elements; (2) real-time interactivity and (3) adding (registering) 3 D virtual elements into perceived augmented reality[11].

With regard to the usage of this innovative technology in the industrial context, many companies are now developing AR applications under a wide range of fields (e.g. logistics, marketing, education, maintenance and other) in order to improve their services [22][21]. As one of the leading technology in the 4th industrial revolution, AR has been recognized as an interesting support of industrial applications including maintenance [16]. In this context, several applications have been proposed in literature. From the most recent works, Masoni et al. (2017) have developed anAR application for supporting remote maintenance operations to improve companies'services. It includes several specific features. The first concerns an inspection module enabling experts to identify the position and the cause of the failure occurred. The second consists on a maintenance recorder module, which allows recording the operation of the maintenance to facilitate the treatment of similar cases or for legal issues.This tool is also based on universal language allowing maintenance experts to communicate together whatever their languages. Further, a remote-Person view is set up in order to follow the work of the local operator. In the same context, Mourtzis et al. (2017) have developed recently an AR application for supporting remote maintenance applied in the robotics industry. Its specificity is to ensure cooperation between the on-spot technician and the manufacturer [19].The exchange of information between the two operators is provided by a cloud-based platform. In addition to that, this application performs the recording of the malfunction by the end user.Accordingly, it indicated the actions required by the expert. More recently, Palmarini et al. (2018) have proposed a systematic review about the current state of art of AR applications focusing on the maintenance context with reporting their most relevant technical limitations. This review included a filter of publications dated from 1997 to 2017. It highlighted the most relevant features characterizing AR applications developed in industry. Those concerns the field of applications; maintenance operation; the devices utilized in the AR system (Hardware); the development platform used to develop the AR system; the tracking technology; the interaction method and the authoring solution to create the contents of AR systems. In addition to the relevant analysis results presented, this article presents some applications examples, among them, we quote those proposed by [7][25][29].

4. Digital twin and augment reality: electrical motor efficiency concept.

4.1. Application strategy concept

The first purpose of this paper is to improve these definitions by introducing a case study in a research area. This work is conducted within the *eRolling*[2] project, it is a collaboration work between industrial (EREM, Fives ...) and academic (UPJV and ESIEE-Amiens engineering school) partners. The objective of this project is to develop a new method of monitoring and detection of forces and failures in rolling bearings in order to adapt this new monitoring technique to higher speeds motor [15]. For this purpose, we considered a bench test that represents the unique industrial prototype that which allows this specific type of tests.

The reason of studying the rolling bearings is that these components are one of the most important in the industrial of rotating machineries. Statistical studies show 40% and 50% of malfunction in rotating machineries is due to a dysfunction of bearings. Electrical monitoring of bearings is a new technique which allows to analyse the influence of the load on this component, but also to detect the presence of defects [15][22].

As a part of this work, we introduce a DT of the bench test concept strategy. The design of DT represent a virtual bench test that gives possibility to test different advanced control strategy while considering electrical monitoring indicator. Figure 1 simplifies the conceptual strategy and the different part of DT.

The principle of the DT Concept is based on the use of a virtual prototype of the real product in order to establish a similar virtual product. This result represent a primary proof-of-concept (POC) and a first step in the predictive maintenance development strategy. In order to establish a DT, one should follow a conceptual protocol. First, create your digital model to simulate its multiphysical behaviour. Second, equip the actual system with sensors that retrieve information that is important (rotation speed, temperature, vibration, etc.). Third, sorting these data to feed the numerical model of the only information useful for the simulation of the client application. We thus go from a numerical simulation of a "generic engine" to a much more precise simulation of the engine in an operational conditions.

Thanks to NX-MCD (Mechatronics Concept Designer) by Siemens new standard, we end up by establishing an academic prof-of-concept of a bench test. From one hand, the resulting DT is a test platform for our academic research in rolling bearings. So, it will be used in different research to analyse various signal, on the other, it had a key role in process cycle of life. While, in this case of study, we will flow the state of the process thanks to AR technologies which offer a full DT integration in its environmental context.

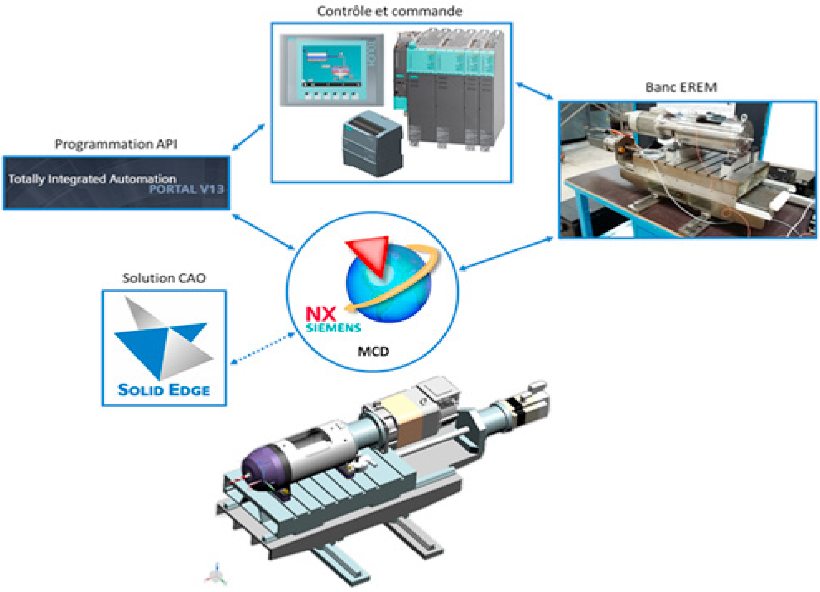

Fig. 1. DT and system interaction for electrical monitoring

4.2. *Digitalization : AR next advanced solution*

As the DT technology, AR has rapidly gained attention worldwide and especially manufacturing [22]. These are key technologies of the industry 4.0 but for AR, the robustness and autonomy of the tools must be improved so that they can integrate the industries and their implementation will have to be lighter while this applications are generally very complex to develop and use, and often require heavy infrastructure to make everything work. In this context, we focus in this section on AR and we to present an industrial POC in Building manufacturing, this concept was ready evaluated in order to be integrate in industrial process. This result is a basic stone to establish a complete industrial process based on AR.

4.2.1. *Example of AR application in Building manufacturing*

We started by introducing a second case study conducted within the ARTBMA (Augmented Reality Technology for Building Management Assistance) project. It is another collaboration work between industrial (ARCOM) and academic (Image Institute ENSAM ParisTech school) patterns.This project focuses on advanced visualization for the industry of the future. It aims to propose innovative and tailor-made solutions in automation, regulation, industrial computing and instrumentation. As a part of this project, we worked on the development of an augmented reality application to support configuration and maintenance of a terminal regulator. This material, manufactured by ARCOM Company, is one of the most components used in the industry in order to ensure the regulation of various terminals such as air conditioning, blinds, electric motor, etc. Hence, the developed AR application consists in helping real operators (technicians) in real time to configure and maintain terminal regulator via augmented reality technology. It can be useful for both maintenance task and configuration guidance. Therefore, it involved two main components. The first is the configuration guidance module, which allows ensuring the connection of the regulator model in real time via augmented reality with taking into account the appropriated diagram wiring. It includes the list of models of the company's regulators.So, for each model, this component allows to determine model description and the assembly diagram generated after selecting the appropriate inputs / outputs to the wiring diagram. Consequently, it allows generating the reference model (the assembly diagram) as illustrated in Figure 2-a.

The second component is the maintenance guidance module. It consists in guiding the technicians to ensure the control and the maintenance of the connected regulator in augmented reality. As a result, the technician will be able to compare the configuration of his real connected regulator with the reference model(as explained above), and therefore

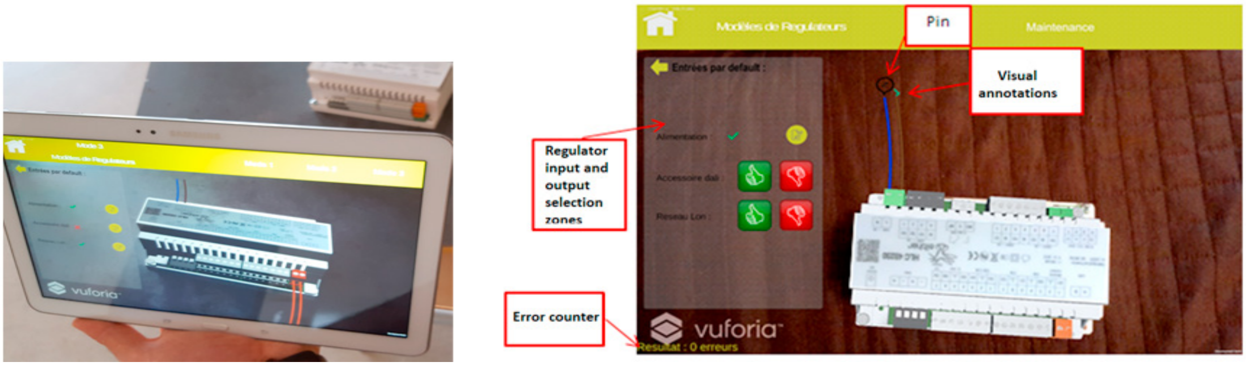

Fig. 2. (a) A screen-shot of the configuration guide module in augmented reality of the terminal controller; (b) A screenshot of the augmented reality maintenance guidance module.

verify the connection (see Figure 2-b). As this figure illustrates, by clicking on the pins the technician will have the choice between two checkboxes. He should click on the green button ”correct” if the cable of his connected regulator (real model) is in the right place, or the red button ”incorrect” if his cable is in the wrong place. To keep track of these checks, he will find instead of the pin a visual annotation. In addition, this module allows calculating the number of bad cables connected, the time of the execution of the task, the number of cliques and therefore to generate the report of results.

In order to proof our concept, we have proceeded to the evaluation phase based on both subjective and objective assessment. In our previous works [1][2], we have proposed a new concept to enable effective integration between subjective and objective evaluations in order to ensure a complete assessment. This concept provides indicator based on ISO/IEC 15939 (2007)[1] allows evaluating a specific usability criterion. It is composed of both subjective measure (captured from a questionnaire) and objective measure (captured from our AR application). This concept provides a procedure for interpreting the results. For our experiments, we have defined several scenarios in order to evaluate the effectiveness and efficiency of our AR application. Users sample was involved 15 participants. The experimentations were took place in a research room at Institute Image EnsamParisTech (France). In order to approve the usefulness of our application to the accomplishment of the tasks of the technicians, we have considered two cases of use. The first deals with performing maintenance and configuration tasks in a quotidian way (paper mode) and the second is based on our AR application. For all experiment scenarios, evaluations results have proven the effectiveness and the efficiency of use of the AR application. It facilitated the technician tasks in both maintenance and configuration phases and provided them a useful guidance tool. For example, the evaluation results of the efficiency indicator of technicians' tasks completion indicated a percentage of 87% of satisfaction and correct tasks completion using the AR application. In contrast, the same indicator noted a very high percentage (70%) of dissatisfaction and the incorrect tasks completion using the paper version.

4.2.2. Interpretation

Through this preliminary work, we have succeeded in proving the utility of this AR application and its effective role in industry. This technology offers advanced visualization of the services of the industry 4.0, which focuses on other technologies like digital twins. This work allowed us to think further and specifically about the relationship that can be established between DT and AR in industry 4.0 and how it can be concretized. In case of predictive maintenance, the integration of these two technologies will got an important role in the industrial process through the predictive detection of anomalies. In order to ensure the predictive maintenance, we propose a new concept described in figure 3. As illustrated in this Figure, the supervisor monitors and checks the status of the system through the DT. He

[1] ISO/IEC 15939.: International Organization for Standardization/International Electrotechnical Commission: Systems and software engineering Measurement process (ISO /IEC 15939: 2007(E)). Geneva, Switzerland: Author (2007).

evaluates the state of the process, interprets the data and establishes the maintenance intervention scenario. Then, he launches the resulting maintenance procedure through the DT. This information will be transported via our platform to operators in real time through AR. In turn, AR will allow them to interact in real time, be in contact with all the process components, and subsequently perform the maintenance phase. Therefore, once the maintenance procedure is done, a report will be generated to the supervisor.

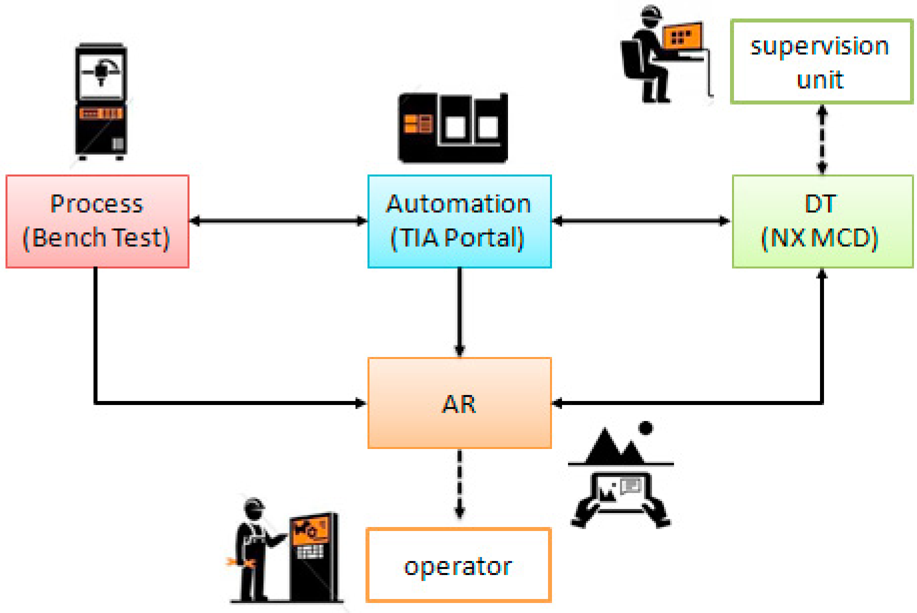

Fig. 3. Proof-of-concept relationship between DT and AR in cas of predictive maintenance application.

5. Conclusions and further work

In this paper, we introduce a protocol of an industrial solution reached within the framework of predictive maintenance. This work is part of a big collaboration between industry and research area in order to develop a DT and AR industrial solution. First, we introduce the context and the motivation of this contribution in relation with maintenance topic. Then, we resume a part of studies that were developed in industrial context. At the final part, we elaborate a POC that was developed in case of industrial application. At this stage, DT concept has already been developed and the AR strategy has been defined (see Figure 3). In further work, AR application will be improved and evaluated in term of robustness, autonomy and usability so that it can integrate and complete this industrial POC.

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