Title:
The Digital Twin, Demonstrating the Potentials of Monitoring of Product/Process: a Case Based on an Agile Manufacturing Control Line

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Keywords:
Industry 4.0, Digital Twin, Product Lifecycle Management, CAD

DOI: 10.14733/cadconfP.2018.377-381

Introduction:
In the recent years, the traditional manufacturing industry is challenged worldwide with the amazing growth and advancements in digital technologies that allow easy integration of interconnected intelligent components inside the shop floor that is at the basis of the so-called Industry 4.0 [12]. The Digital Twin (DT) can be seen as an integrated data, model and tool system to trace a current product/process throughout its lifecycle. It transforms the data into usable information for diagnostics or other engineering activities [9]. The DT was first born in the aerospace field and only recently has been adopted also in manufacturing contexts: such a term is used in industrial environments and in governmental research initiatives. Methods of industry 4.0 are not widely implemented in manufacturing operations.

The current challenge in manufacturing engineering consists in the innovative integration of the product/process and the related data management and tools, aiming at synchronizing the product and process. Therefore, professional and academic education is necessary for implementing industry 4.0. This paper focuses on a definition of digital twin as practical as possible and a prospective case analysis on an Agile Manufacturing Control Line (AMCL) at the design stage to demonstrate industrial/academic users about the potential and efforts of implementing cross linking technologies.

State of the art:
Even if the Industry 4.0 is only a recent industrial topic, an extensive literature is already focused on this topic and its hypothetic scenario evolution. In some of the available studies, a significant diffusion of enabling technologies for Industry 4.0 is predicted [7]. Nonetheless, just their implementations are not expected to be able to transform the old production systems in Industry 4.0 ones [11]. In particular, according to [14], the main element featuring an industry 4.0 system is the presence of the Cyber Physical System (CPS) paradigm, the Industrial Big Data, IoT Internet of Thing (IoT) and the Digital Twin (DT). The relationship between these components is characterized by a high complexity and different configurations, each one of them connected to a specific objective [6]. However, to make possible this behavior, it is recommendable and necessary to implement three capabilities to the CPS: intercommunication ability between CPS through the IoT for allow a continuously exchange of data, a comprehensive knowledge of the system state and, most of all, a computational and autonomous

ability [2]. As said above, Industrial Big Data [5], DT [10] and IoT [3] play a critical role in embodying all these capabilities. According to [8] and [4], a system may achieve its autonomy in industrial production process decision-making with the help of a DT which could replace the production system time by time. In this context, arise the importance of the DT in the Industry 4.0 revolution, as a necessary step for improving the self-adaptive behavior of the interconnected CPSs. As a matter of fact, despite the substantial investment, it is possible to show that the implementation of a DT allows exponential improving of production quality [1]. Several authors describe the implementation of DTs developed with different mathematical methods. Grounding a DT modelling on the use of simulation software is not an original idea. For example, [13] focused their attention on an agent-based simulation approach with the introduction of "Experimental Digital Twin" concept. The results have been very encouraging and, the proposed approach shows its feasibility and promises in a manufacturing environment. In short, the use of the DTs concept, allow a practical integration of the simulation, like the Discrete Event Simulation (DES) in the manufacturing context.

The agile manufacturing control line's digital twin experiment:

To build, implement and apply a DT proof of concept focused on the Industry 4.0 paradigm, a simple agile manufacturing control line (AMCL) was built. Agile because it is a demonstrator of packaging for many products as the AML SYSTEM's product and the entire production line can be modified according to what we want to do and obtain. It consists of four processing stations, the circular conveyor, the weight control, the robot cell and finally the coordinate measuring machine (CMM). All the stations are connected through a defined circuit, the AML system product's flow is between the different processing components (Fig. 1) so, starting from the circular conveyor, passing through the weight control and then the robot cell. It should be noted that the role of the circular conveyor is to distribute the product at the beginning of the line; the linear conveyor in which it appears a weight control should test if the product is compliant regarding its weight; the robot cell inspects all the other aspects and the CMM tests the quality of the product and the reliability of the other stations.

For the real construction of the system, "ERM automatismes industriels" has been selected for building the first three workstations. The circular conveyor is made of a rotating table on which a rotating metal plate and a rotating rod are in contact. The scope of the rotating rod is the transfer of the product to the next step. This workstation is feed by a motor of 400 watt. The second workstation is the linear conveyor composed of the critical part which is the weight control. The compliant products should have their weight between the minimal and maximum threshold weight value. The working mode of this part can be continuously or intermittent. The industry 4.0 concept here should take into consideration the fact that the presence of the human being is not necessary for eliminating the non-compliant products and also to process the operation. The third workstation, the robot cell, is made by the company KUKA™. And finally, the last part, the CMM, is produced by Mitutoyo™.

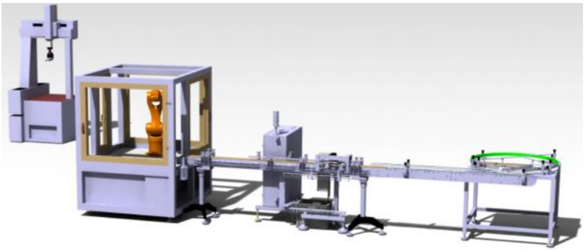

Fig. 1: Agile Manufacturing Control Line (AMCL) Digital Mock-up of the Sorbonnes Université, université de Technologie de Compiègne, DT Industrie 4.0 platform.

Engineering simulation has traditionally been used for new products design and virtual testing, eliminating the need to build multiple prototypes prior to product launch. Now with the emergence of (IoT), simulation is expanding into operations. The IoT enables engineers to communicate with sensors on an operating product or component to capture data and monitor operating parameters. The result

Proceedings of CAD'18, Paris, France, July 9-11, 2018, 377-381

is a digital twin of the physical product or process that can be used to monitor real-time prescriptive analytics and test predictive maintenance to optimize asset performance. The digital twin also provides data that can be used to improve the physical product design throughout the product lifecycle. The application of digital twin will build on the component approach with UTC team aiming to deliver a fully integrated solution to structural monitoring for improved reliability of product/process. A condition monitoring system will encompass the entire physical control line providing ongoing structural analysis. Simultaneously, this will be mirrored virtually with the creation of a 3D model of the AMCL in the form of a digital twin, including input from different sensors positioned across the physical entity and from the QRcode positioned on the product, to continually feedback monitoring data. The output will be fully comprehensive, real-time assessment of the structural condition of individual production line assets.

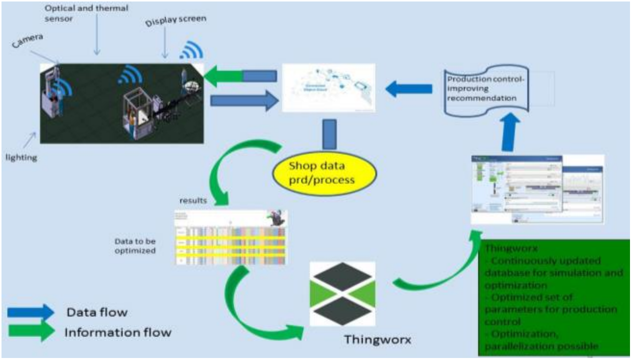

Fig. 2: The Digital Twin concept.

<u>Monitoring and scenarios:</u>

The integration of condition monitoring is crucial to develop a robust, condition-based maintenance strategy or predictive maintenance approach for machinery and equipment used in our AMCL. Condition monitoring starts with using permanently installed sensors to collect data which is then used to analyze changes in the performance or condition of AMCL's components and product while it is in operation. Any change in the performance or condition of the component that deviates from its standard parameters can be an indication of early-stage wear, deterioration, bad working, etc. Condition monitoring not only describes the present state of the product/process, but also provides objective data which can be interpreted to predict its remaining useful life while in operation. Operators can use this knowledge to shape maintenance schedules and inform component repair before catastrophic failure occurs. Condition monitoring, therefore, plays a vital role in both avoiding unplanned shut downs and in calculating the life expectancy of an overall plant. By using software as those made by 3DS Dassault Systèmes™ or another one in the kind as PTC-Thingworx™ physic-based simulation in conjunction with analytics, we can make confident predictions about future product performance, reduce the cost and risk of unplanned downtime and improve future product processes.

Focusing on the conceptual design shown in the figure above, for having the industry 4.0 characteristics, the robotic, electronic, mechanic fields were explored. Therefore, many devices have been added to our system, as sensor, video cameras, lighting and also some extra component as a mechanical arm for helping to the part positioning. The real and correspondent DT system is designed for operating in 3 different decisions making logics (scenario) correspondent to 3 different behaviors.

Minimization of the Processing Time, in which the real system will cooperate in the scheduling of the plant, preferring to assign less consequential operation possible to a processing workstation.

In this context, a common cycle time can be given which restricts process times at all stations.

Simulating the system, we could decide to apply an intermittent movement because the workpiece should come to a full stop at each workstation and should be automatically transferred as soon as a

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given time span is elapsed. Alternatively, applying a continuously advancing material as conveyor belt which forces the end of the operations before the workpiece passes to the next operation.

For both modes, we could have incompletion tasks, so a synchronization of the table's velocity and the linear conveyor one could be an issue. Using the digital twin, we should be in grade to overcome this problem because with the simulation, we will test the system, checking for different speeds and adapt them according to our need. Therefore, when a workpiece would pass through the circular conveyor, we should avoid a bunch of product at the input of the next station. And the actions at the other stations would be synchronize according to the input speed. Pre-Planned Policy, in which the AMCL represents the system without its ability to think. It represents the old traditional scenario of industry with a centralized planner:

First, it is possible to use the DT for the development of the future system. In this context, the DT has itself the same rules and structure of the future equipment (i.e. It represents the virtual substitutes of the real object with the same code and behavior). This scenario allows simulating, developing, characterizing and verifying, the behavior that the real object will show inside the manufacturing system. So according to this paragraph, the first scenarios can be to represent the entire factory in the software, and for this, we can use Dassault System Software, simulate it and look how its behavior is. Thanks to the complexity mastery of the virtual object, we would be in grade to implement the real object looking out to its characteristics and specificities according to what we simulate. So, DT allows conceptualizing our system. The capability of the DT lets us directly see the situation and eliminate the inefficient and counterproductive mental steps of decreasing the information and translating it from visual information to symbolic information and back to visually conceptual information. With the DT to build a common perspective, we can directly see both the physical object information and the virtual object information, simultaneously. The use of DT can help to manage our factory safely. The data that we get from our DT should be compared with those in our system in other to find disparities. When we have the virtual product information and the physical product information separate, we can compare them. With the DT model, we can view the ideal characteristic, the tolerance corridor around that ideal measurement, and our actual trend line to determine for range of products whether we are where we want to be. Tolerance corridors are the positive and negative deviations we can allow before we deem a result unacceptable.

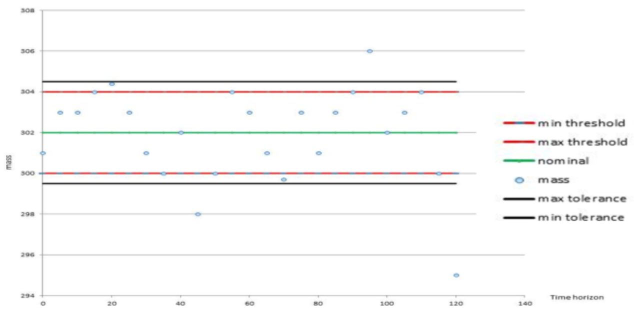

Fig. 3: Preventive maintenance of product in the weight control.

Depending on how we implemented this capability, we could see the differences in terms of color, with mass color progressing from red line to black line, we are in our tolerance corridor and there is no difference. Past the black color, we are beyond the tolerance corridor. If it happens that we have a series of good products followed by one of scrap product, as we can see (Fig. 3), so we have a disparity, the system warms us and then, we can make instantaneous decisions about the differences or an operator can interact directly with the system to change something manually. This interaction allows us to compare and adjust future operations. So, it will help us to reduce maintenance failures, reduce maintenance costs, predict failures, optimize operation flow and allow focusing on opportunities as increase of productivity and improving of the quality.

Conclusion:

In this paper, a proof of concept to show the benefits of automated data acquisition (monitoring), processing and the DT of an AMCL is presented. Benefits of monitoring for the analysis and modification of production systems can be experienced by a practical training session, especially continuous data acquisition, by informing root cause analysis, when to take preventive action to avoid failure and assessment of a component's full life cycle capacity. It enables to manage risk more effectively, and to optimize their maintenance and service activities. This leads to increase reliability and production output, helping to eliminate unplanned shutdowns and minimized maintenance costs.

Acknowledgements:

The presented work has been possible thanks to ERM, AML systems and DIMEXP (ANR LabCom UTC/DeltaCAD) who has designed and made the production line.

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