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A holistic methodology for development of Real-Time Digital Twins

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Abstract

The Digital Twins of product and production face the challenge that once the development process is closed, they does not reflect the real status of production where events as equipment failures, poor quality or missing compound parts happens continuously. For assuring production resilience a holistic methodology, combining a top-down with a bottom-up 3D scanning approach for capturing real-time production parameters and embedding them in Digital Twins is developed. The paper presents the methodology and a motivation scenario for further validation in an innovative set-up of an automated measurement cell, where state-of-the-at technologies as autonomous AGV, mobile 3D laser scanning and automated processes are integrated.

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1. Real-Time Digital Twins approach

The guiding idea of the research team is to realise the Real-Time Digital Twins concepts [1,2], technologies and applications and their validation in operational factory environment, towards the achievement of the factory optimum, such called factory resilience planned to produce at optimum [3], and to promote it as standard-based method.

The proposed approach (Figure 1) consists of a Factory shop floor populated with scalable networks of technical and human sensors—an approach based on the anthropocentric “humans as universal sensors” concept - providing context-data on primary factory objects (humans, machines, equipment, tools, devices, parts, etc.) and a Space of Factory Real-Time Models which are shared and queried by factory applications. State-of-the-art sensor systems, wireless communication, and mobile device technologies - herewith called Cyber-Physical System Technologies (CPSTs) will allow the capturing of the current status of factory objects such as materials, parts, machines, equipment, tools, people, etc. from the Factory’s Shop Floor. Simple factory objects endowed with smart sensors will be treated as *smart factory objects* [4] and the information thus collected will be referred to as the *context* [5] of a smart factory object. The context consists of physical information (location, movement, energy consumption, temperature, pressure, etc.), logical information (identity, privileges, and preference), interrelationships with other domains, and a history of the object along the time scale.

For example, the following context parameters can be considered: ID, Type (e.g., Chiron), Status (e.g., *In Failure*), Date Time (e.g., *16.02.2016 13:25 CET*), Position (i.e., *x=200, y=150, z=725*), Relation(s) to other factory objects (e.g., *Product: 459XY, Production order: TTT56, Order priority: Very high, Drill Tool T45V, Rotation speed: xyz rot/min*), etc.

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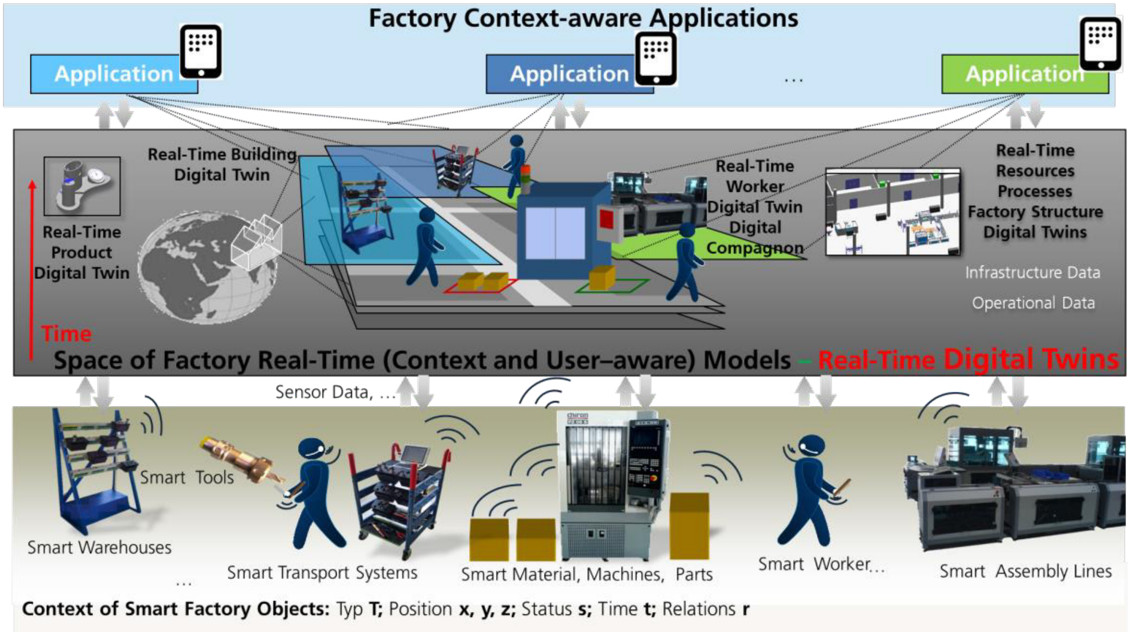

Fig. 1. Concept of Space of Real-Time Digital Twins.

This way the factory will become a network within which every device can be linked to the end of providing its information to any user interested in these data. A very large amount of context data will be captured by a wide range of mature, commercially available, well understood and accepted CPSTs. These can be combinations of tags (RFID, barcodes, etc.), portable computing devices (e.g., tablet, PC), and smart sensors (mobile 3D laser scanners) deployed in the factory shop floor.

The models of smart factory objects such called **context and user-aware models** will be available in a repository named **Space of Factory Real-Time Models.** The **Product, Process, equipment, Building and Factory Data Models** will thus be extended by dynamic context data about the smart factory objects, such as the objects' location, movement, status, etc. The models will be enriched by **temporal aspects** respectively by attaching historical information to the context data. These models are further on called **Real-Time Digital Twins.**

The Space of Real-Time Models will build the foundation of **Factory Context-aware Applications** [6], which will provide decision support by constantly monitoring the status of the factory smart objects in real-time. Thereby, the applications will be able to act upon and adapt to changes in the shop floor, and select and present information depending on the applications physical context. They can share the wide range of context models from the Space according to their aim, e.g. real-time monitoring of energy use, material flow, quality, machine conditioning, etc. Based on the enrichment of the context models by temporal aspects, these applications can query not only the current state of the factory objects, but also states of the past or even predicted ones in the future, e.g. through online simulation.

2. Holistic methodology for development of Real-Time Digital Twins

2.1. Research procedure and motivation scenario

In order to implement the Real-Time Digital Twins in operational manufacturing environment, the research group approaches a *bottom-up procedure*, addressing the theme in four steps. In the fist step, identification of at least two motivation scenarios coping with the challenge of giving life and real-time to the Digital Models of physical manufacturing entities from factory shop floor, e.g. parts, components, equipment, tools, devices, human workers, etc.; is done. The validation of the motivation scenarios (Step 2) with state-of-the-art enabling technologies is followed by (Step 3), development of a generic approach for Real-Time Digital Twins in manufacturing. the (Step 4), development of the Road Map for migration of the generic approach in other industries and use cases, e.g. machine tool/equipment industry. Additionally, the employment of other context capturing technologies, e.g. smart wireless sensors, will be considered as well.

The motivation scenario presented in this paper consists of the *Measurement Cell*, dominated by robotics and autonomous vehicles (AGVs) and surveilled by 3D capturing and sensing technologies. The overall objectives of building and validating this scenario is the improvement of the quality of the body in white components towards zero defect manufacturing in automotive industry.

The created layout of the Measurement Cell, presented in Figure 2, consists of the following main components, highlighted in Figure by their numbers, as follow, (1) Industrial robotic arm (KUKA, KR360 R2830);

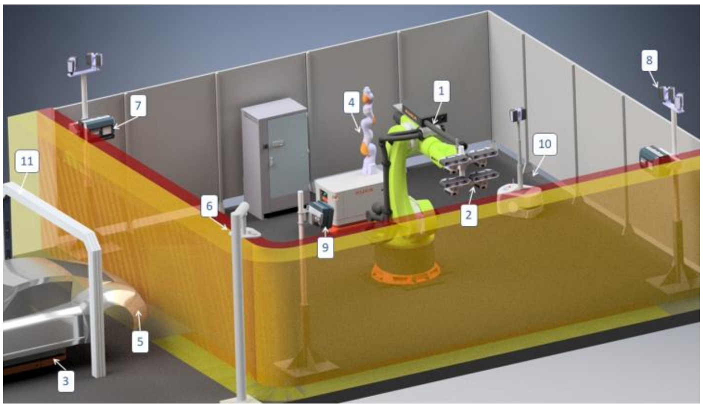

Fig. 2. Layout of the Measurement Cell.

(2) Laser scanner for measurement of body shells/attachments coupled on industrial robotic arm (Cobalt, KUKA KR360); (3) AGV for parts transport (KUKA, KMP1500 FTS); (4) Mobile industrial collaborative robot (KUKA KMR IIWA); (5) Part, body in white (Mercedes S Class); (6) Safe camera system for monitoring safe rooms (PILZ SafetyEYE); (7) Laser scanner for measurement and projection on surfaces (FARO VECTOR); (8) Laser scanning for measurement of painted bodies (FARO FOCUS); (9) Imaging Laser Projector (FARO TRACER); (10) Mobile 3D laser scanner (FARO ScanBot); (11) End of line measurement gate for buckling dents (FARO Quality-Gate).

The **process flow** of the performed activities in the Measurement Cell consists of the following steps, where the involved components from the Layout presented in Figure 2 are marked with numbers:

Step 1: The KUKA AGV (3) transports the Mercedes body in white (5) from outside of the layout area into the cell;

Step 2: The KUKA industrial robotic arm (1) measures the body quality on one side of the body through the Cobalt laser scanner (2);

Step 3: The KUKA mobile collaborative robot (4) measures all other sides of the body (5) where the fix KUKA industrial robotic arm (1) cannot reach the body;

Step 4: The PILZ SafetyEYE (6) monitors the cell for safety issues, while the cell is open on the left and bottom sides as in yellow and red colors is in Figure 2 is highlighted. The yellow area will trigger an alert and the red one will stop for safety reasons all processes into the cell;

Step 5: The FARO VECTOR (7), FARO FOCUS (8), and FARO TRACER (9) capture continuously the quality of the processes performed in the cell, on a *fixed* and *top-down* frame;

Step 6: The FARO ScanBot (10) scans the whole cell in a *mobile* and *bottom-up* frame;

Step 7: After the measurement operation performed on the Step 2 and Step 3 are accomplished, the KUKA AGV (3) transports the Mercedes body in white part (5) outside of the cell by passing throw FARO Quality Gate (11) where the final high-precision quality measurement is performed.

The activities of the Steps 2-6 are performed simultaneously being followed by the final Step 7.

2.2. Enabling technologies for Measurement Cell set-up

For the realization of the Measurement Cell, the research group employed a number of state-of-the-art technologies in the field of mobile/autonomous industrial robotics, projection systems, 3D laser capturing, which are comprehensively presented in the following paragraphs.

Industrial robots [3] are automated equipment, capable of movement on three or more axis and they can be programmed in various ways. In laser scanning quality check [7], an industrial robot can follow a defined trajectory with respect to the part that needs to be measured, multiple times, with the same precision.

Automated Guided Vehicles: known as **AGVs**, are used in industry for logistic operations. There are multiple types of AGV's considering their uses and navigation capabilities. Processes like towing, loading and transporting are performed autonomous by following a cable, a tape, a laser or even a wireless interfaces configuration. Parameters like maximum load, battery autonomy, and maximum velocity, recharging time, safety measures and position accuracy must be considered when modelling an AGV.

3D laser scanning: a relatively new technology, used to increase productivity and collect 3D data to optimize and simplify the work flow [8]. In the last years, there has been major progress with its implementation in industry, mainly for quality check processes, but also for reverse engineering products and facility management. To have relevant data, the scanning parameters must meet the modelling demands. Therefor the scanning rate, speed, resolution and distance must be considered in 3D industrial laser scanning.

Safety camera systems: when working with automated processes, defining a safety area is mandatory. Even if all the machines were set up correctly and installed properly, there is always a slim chance for an unfortunate accident, due to human error or incorrect software development. To solve this problem, the perimeter around the working station/cell, can be surrounded with fences. A more innovative way would be using a sensory based system. This way, the restricted area can be defined in real time, offering flexibility and a higher safety level.

2.3. Holistic methodology and solution

The holistic methodology and our solution for the realization of the Real-Time Digital Twins is presented in Figure 3. The Figure represents on the bottom the factory shop floor where equipment, tools, devices, parts, etc. are monitored in real-time by capturing their *context* through technologies like smart sensor "*factory objects*" is represented by: a) **Type T**, e.g. KUKA robot; b) **Position x, y, z** in factory layout; c) **Status s**, e.g. 0=not working, 1=working; d) **Time t**; e) **Relations r**, e.g. the *KUKA robot* processes *measurement* of the *Mercedes body in white* with a *high priority order* and a *accuracy* up to 100µm. On the middle layer of the Figure the context aware Models of the factory objects are realized by using technologies and systems from the upper layer, e.g. CAx for modeling the products, 3D laser systems for capturing the real time context of the factory shop floor.

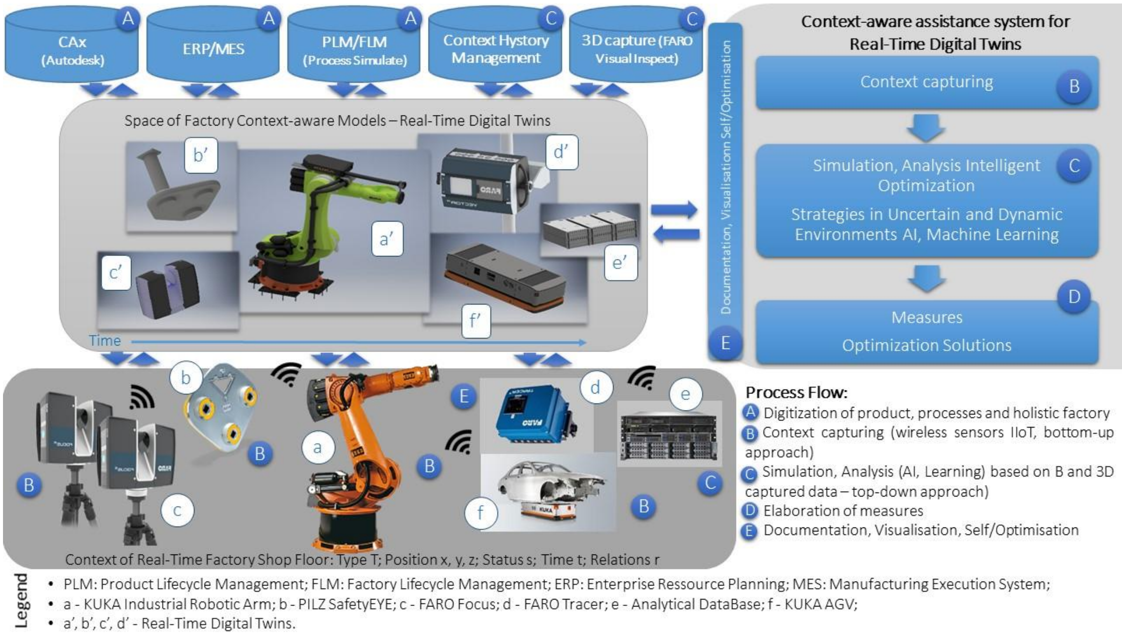

Fig. 3. Holistic methodology and solution.

On the right in Figure 3, the Context-aware assistance systems for Real-Time Digital Twins is represented as the **solution** envisioned by the research group. It consists of few components represented in Figure 3 in boxes and detailed below as follows:

Step A: In the first step of the process flow, all factory objects, e.g. industrial robotics arm, mobile AGV, 3D laser scanning, parts, etc. are modelled by using digitalization systems like CAD for the product design, Digital Factory for layout creation, etc.;

Step B consists of data acquisition through e.g. wireless sensors and/or laser scanning, using a *bottom-up* approach. This process is also known as *context capturing*;

Step C: Simulation and analysis process represents the next step performed after enough data in real-time is captured. Using 3D captured information and having the production history data, an optimization algorithm based on machine learning technology can be applied to develop further optimization solutions or measures aiming at continuously improvement of key production parameters, like in our case the quality of the product;

Step D: Elaboration of measures for optimization of the performed processes represents the final step, accomplished by documentation and visualization. The last can be performed through a report or even by a laser projector right in the factory floor. Additionally, some mobile devices as iPad, iPhone can be used for sending triggers, alerts to the worker operating into the production area, in our case outside of the cell. Based on these measures the semi-automatic or self-configured optimization of the cell is realized.

3. Conclusions and future work

The performed work started with a new concept on giving Real-Time feature to the Factory Digital Twins, followed by definition and set-up of a motivation scenario. Next activities will focus on defining the second motivation scenario in the field of Digital Twins for carbon fibre 3D printing process. The validation of both motivation scenario, the development of a generic approach for Real-Time Digital Twins in manufacturing and the development of the Road Map for migration in other industries and use cases are planned as well.

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