Digitally integrated, automated 3D scanning with CAD reconstruction

Reverse engineering (RE), sometimes misunderstood as copying rival products, is one of the engineering tools whose importance will continue to increase strongly in the coming years. Although they have been in use for quite some time, a large number of activities used to create models of existing components is based on manual processes that are highly dependent on know-how. The further use of the models, for example in CAM systems, is also manual and involves a large number of repetitive tasks for the user to generate the NC code. The scan-based system described here is dedicated to automated scanning, model preparation and provision for subsequent processes. The challenge of using low-cost scanning hardware could be met here. In a comprehensive automated repair process, this scan unit can be used independently of components. **Stephan Mönchinger, Christian Masuhr, Elisabeth Brandenbur and Rainer Stark** explain the process

Introduction

The personalization and customer-specific adaptation of existing products as a partial aspect of the megatrend of new digital business models, require technology like 3D scanning as an initial process step. These are necessary elements, if digital Models are not available or do not match the present condition of the product as-built, since it provides the raw data required to create virtual instances of real product features. Product features are subsequently needed to generate a further processable representation of digital twins, since the models of products do not cope manufacturing tolerances and changes from use, but are represented by master models. 3D scanning is also an integral part of the growing recycling economy; as the reuse, processing or recycling of products, for the purpose of adaptation or repair, also require the provision of a virtual representation of the real state of construction [1].

Digital twins of technical systems and services are already being used in the digital factory by creating instances of digital production facilities. These comprise three essential aspects of smart manufacturing: real-time condition monitoring, control and simulation [2].

A digital twin of a cyberphysical production system consists of a digital master (e.g. Models), its shadow (e.g. real time data) and an intelligent combination of the two [3]. Master data can be development artifacts of the production system and the product (e.g. layout or process sequence), since a production system is closely linked to the goods to be produced. Shadow data are always connected to a specific instance – the real object in the reality – and could be provided by sensors, identification ma ks or manual entries. An example of a sensor of this kind is a scanner, which generates point clouds of a surface. This is most efficient w y to get a digital representation about the real shape of 3D geometries. To be able to link this data with the models in the master of the digital twin, however, they must be of the same shape. The necessary kind of adjustment is associated with manual effort and expense.

Digital networking along the production chain and the automated generation of individual product features by 3D scanning should hence be promoted as a partial aspect of the digital factory of the future. CPS and CPPS interaction, contains components of mechanical, electrical hardware and software. There are many objects in the factory for which there is considerable added value, if there is a digital twin. For the digital counterpart it is essential to know the actual state. E.g. Product Lifecycle Management, Enterprise Resource Management, Supply Chain Management rely on this information to make the best decisions and save resources. In detail a more exact planning, analytics and a diagnosis of failures are possible. Scanning can be used as a link between a digital factory twin and physical objects without having the access to their respective models.

We need these elements as an interface, beyond the pure models, because in the reality deviations from the models can occur at any time. There is a potentially infinite umber of influencing facto s that are not all taken into account in the generated models in the product creation process. Scanning enables an interface to merge the disruption between heterogeneous systems, e.g. when analog systems are successively expanded or unforeseen deviations occur.

Adaptation to changing environmental conditions leads to resilient systems. By knowing the true shape of a manufacturing system, wear of components can be detected, which leads to quality assurance by ensuring process capability. It is possible to enrich automatic simulations with real-time data. Customized products can be made possible by an automatic reorganization of batch-one production systems [4].

There are elements where you need to know exactly what the component looks like and where a digital solid body necessary. The commissioning of automated systems is a particularly relevant application. A bidirectional interaction with factory twins is only possible on a real data basis, e.g. to achieve collision detection. There is the problem in industry that models are not completely maintained and are very company specifi , which is the reason why information model standards have to be made for everything. The state of a real plant in production is constantly changing, with direct effects on profitabilit . Already today there is a data basis consisting of planning data, PLC and scans, but here again raw scan data cannot be processed. Only manual merging makes the results of a scan usable [5].

The necessary investments in suitable scanning systems are difficult t manage for many small and medium-sized enterprises (SMEs), with expenses well over 100,000 € for the industrial near-standard. In 2019, for instance, the general investment investment propensity of Berlin SMEs has weakened. However, the investment focus is not directed towards new technologies. At 57.8 % of the asked companies, expansion investments are the main focus of investment activities, although they have recorded the sharpest decline of 6.4 % compared to the previous year [6].

Smaller companies in particular are often looking for low-risk solutions. The intention or the means to bear the economic risk for integration into an application without having seen a working example beforehand is correspondingly low.

Technologies in the context of Industry 4.0 and their applications often only result from the combination and intelligent interconnectedness of several technologies.

It is therefore difficult to presen the benefits of a single technolog without an application-related context. For this reason, the Berlin Fraunhofer Institutes IPK, Fokus, HHI and IZM, within the framework of the joint cooperation Berlin Center for Digital Transformation (Leistungszentrum Digitale Vernetzung (LZDV)), are rising to the challenge of demonstrating novel interaction, virtualization and manufacturing technologies in an application-oriented manner in the production environment of tomorrow (Produktionsumgebung von Morgen (ProMo)) project [7, 8]. Based on selected process steps of a maintenance, repair and operations (MRO) process chain, different technologies of the participating partners are integrated in order to demonstrate the interconnectedness and flexibilit of the individual technologies as well as the resulting added value to the industry. The digitalization of the process steps is shown by the example of the repair process of single components (turbine blade, forming tool) by means of additive and subtractive methods, using real production machines. 3D scanning is used in the ProMo project

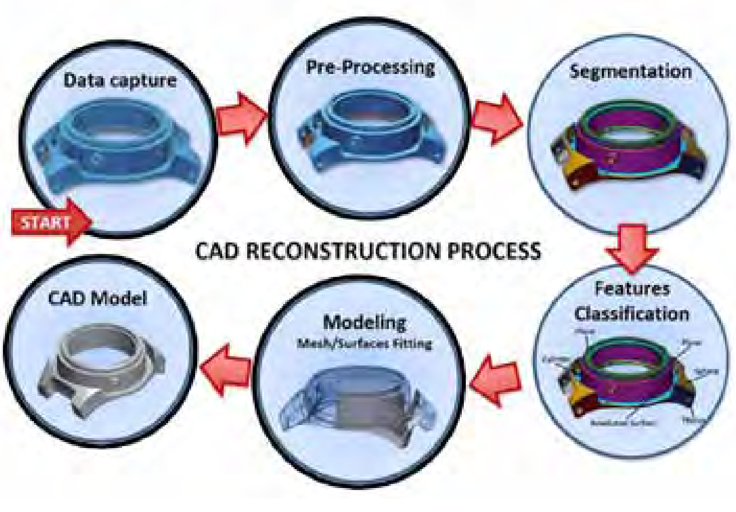

Figure 1: Automated RE process: Reconstruction using the example of a watch case [6].

Bold frame: considered in more detail below

Tab. 1: 3D-Scanner features and key figures

Figure 2: Einscan Pro 2x from Shining 3D

Property	Value
Accuracy	0.02 – 0.04 mm
Volumetric accuracy	0.1 + 0.3 mm/m
Distance between measured points	0.2 mm
Scanning speed	30 fps; 1,500,000 Points/second
Working distance	400 mm
Scanning method	Projected structured light, manual
Weight	1.13 kg
Price	Under 10,000 €

for verification with the focus on determining the real geometry and comparison with a target model. Furthermore, reverse engineering can also be used for the design of new products, the modification of existin products or the recovery of lost design data [9].

Material and Methods

In general, automated, scan-based reverse engineering is characterized by six consecutive steps (Figure 1). First, geometric data of the object to be virtualized must be recorded. This must then be post-processed and segmented. Next, the generated data can be classified and used as inpu for model generation. The result is a CAD model.

In non-automated processes, reverse engineering involves a large number of manual, repetitive and highly know-how-dependent activities. Automated acquisition systems are often associated with high investment sums, are not yet available in an industrial context or are currently only being developed for certain application purposes [10, 11]. The post-processing of the scan data is often done manually. The connection (tessellation) of the scan data creates a representation of the surface. For further usage of the data, the data has to be transferred into mathematically described models. This is mainly done by manually reconstructing a CAD model from the tessellated surface model. The cycle times and the quality of the results vary depending on the level of knowledge of the executing person. Therefore, the ProMo project is working on the automation of these process steps.

The ProMo demonstrator integrates qualified and interconnecta le individual modules to ensure the configu ability of application-specific solutions. The EinScan Pro 2x of the company Shining 3D is used here as a generic scanning device (Figure 2). The specifications of the scanner can be taken from table 1.

As a non-contact scanning system, the scanner is generally characterized by fast data acquisition, financial sustainabilit and sufficient accu acy [7]. The scanner, with its costs of less than 10,000 €, is a cost-effective alternative compared to more expensive quasi-industry standards with costs of more than 100,000 €. The measuring accuracy of the system is specified y the manufacturer as 0.04 mm. This could be increased to 0.02 mm by suitable calibration of the demonstrator. The measuring point distance is a minimum of 0.2 mm and the minimum distance to the scan object is 360 mm. With these characteristics, the scanner is suitable for virtualization, with subsequent feedback. The feedback model is accurate enough for a subsequent repair by means of additive methods. The device is still a hand-guided system based on structured light projection. In general, structured light systems have a better resolution (measuring point distance) and a higher accuracy (absolute) compared to laser triangulation systems. Portable devices are light and small in size and therefore offer a high degree of flexibility in use [9] The scanner is guided by a robot by means of an end effector manufactured in a rapid prototyping process (Figure 3).

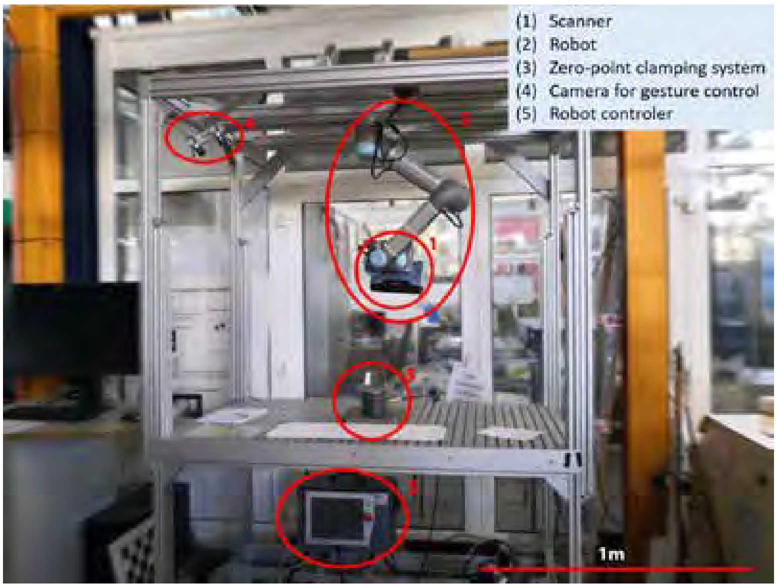

Figure 3: Digitizing system for semi-automatic measurement and nominal/actual comparison of the component

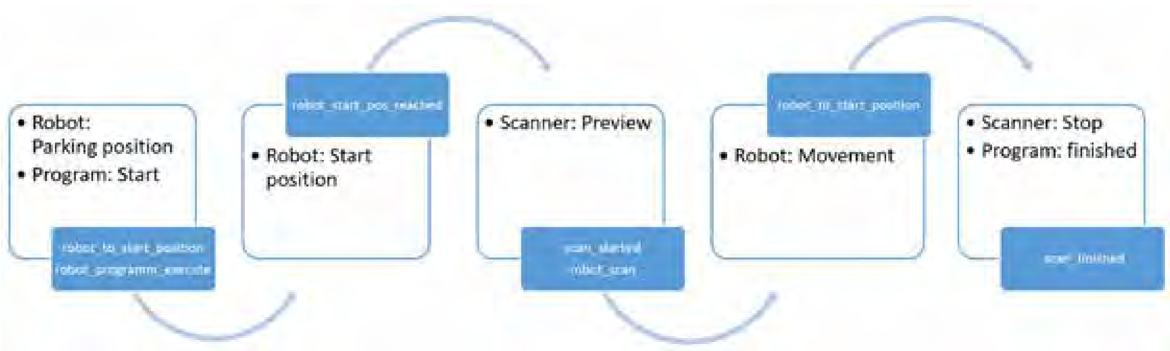

Figure 4: Program flow and flags for automated scanning

Automated Reverse Engineering Process

The guidance of the scanner by a robot enables the use of individual, automatically generated scanning courses. Depending on the definitio of the damaged area via gesture control, the scanner can be guided around the component in a suitable manner. Start and end of the scanning process are triggered by UPC UA signals (flags) (Figure 4) Robot and scanner exchange these signals, the robot's motion path can be individually adapted and programmed via gesture control.

If the robot is in park position and the program is executed by the user, it moves to the start position for the scan. At the start of the scan process, a specially developed Python script is initiated, which executes the scanner's proprietary software (Shining 3D EXScanPro) connected via a ZeroMQ interface. An in-house development is used to visualize the scanning process, since the manufacturer's software does not provide a suitable visual interface. As soon as the software is executed, the robot moves along the generated path. When the movement is completed, the scanner stops and a signal to the robot is triggered. The robot then moves into parking position. Once the scanning process is complete, the data is networked within the manufacturer's software and stored in stl format to make it available for the subsequent process. The transfer of the data can be implemented using 5G technology, for example. In this case, larger data volumes can be processed using a central processing unit and subsequently made available to the process again. This means that it is no longer necessary to provide local computing capacity.

For modelling, the actual and target data set must fi st be superimposed, i.e. globally oriented to each other. Algorithms developed by the Fraunhofer IPK are used for this purpose. These are able to determine common geometric properties within interconnected data sets and then automatically align the components. The algorithms are based on PCL (Point Cloud Library) functionalities that have been adapted for this application. Once the data sets have been automatically aligned, the next step is to create a difference model using a script integrated in Siemens NX. For this, the data sets are subtracted from each other by Boolean operations. The result is the positive of the volume difference between actual and target model. This must then be converted into a volume model and can then be transferred to the CAM program via an interface. There the numerical code for controlling the system is final y generated, which is used to repair the component.

Conclusion

Through the symbiosis of the individual technologies, a significant y increased efficiency of the M O process chain is achieved, which continues to focus on people and their process knowledge. The developed partial solution for automated virtualization by 3D scan shows a multitude of economic advantages. Firstly, the necessary investment, compared to conventional industrially applied scan solutions, is low and also justifia le for small and medium-sized companies. Furthermore, there is a significan increase in the degree of automation compared to the highly manual previous virtualization process. This is accompanied by a reduction in processing times, which in turn means that the downtime caused by the failure of the component to be repaired is minimized. This is reflecte in an improved OEE (Overall Equipment Efficiency) index The utilization of know-how carriers and specialists, in view of the increasing shortage of specialized workers, is significant y reduced and employees are relieved of repetitive tasks. Modular and configu able process sections allow the process chain to be adapted to the boundary conditions of the respective application. Due to the intuitive, user-centered operation, the inhibition threshold for users is significant y lowered. However, the user always retains the role of decision-maker.

The improved resource efficienc is ecologically advantageous. With regard to the entire automated MRO process of the LZDV project ProMo, material consumption is reduced by the targeted application of material in the area to be repaired. In addition, this results in lower removal volumes in post-processing, which leads to increased tool life. Finally, the reduced costs of the repair process improve its economic efficiency compared t a new acquisition. This means that a repair that is still uneconomical today can become more cost-effective than a new acquisition. This helps to save resources and avoid waste. Finally, an optimal production process can be achieved through continuous networking, also by means of 5G technology in production.

Funding information
The results of this project were developed within the framework of the Berlin Center for Digital Transformation funded by the Berlin Fraunhofer Institutes. Due to cancellation of the Hannover Fair 2020, the digitizing station will be presented for the fi st time later in 2020.

Authors' Profiles

__Stephan Mönchinger, M. Eng.__, born in 1991, studied mechanical engineering with a focus on construction technology at the Beuth University of Technology Berlin in association with Siemens AG. He completed his subsequent studies in mechanical engineering with specialization in production systems with distinction at the Beuth University of Technology. Since 2018 he has been working at the Fraunhofer Institute for Production Systems and Design Technology as a research assistant in the Virtual Product Creation division, in the Model-Based Development department. His research focus is in the field of r verse engineering, especially on the automation of the reconstruction of 3D CAD models from 3D scan data.

__Christian Masuhr, M. Sc.__, born 1992, studied mechanical engineering at the University of Paderborn. He works as a research assistant in the Virtual Product Creation business unit at the Fraunhofer Institute for Production Systems and Design Technology IPK Berlin in the Model-Based Development department and has been working there since 2019. His research focuses on digital product twins, the digital factory and smart hybrid prototypes for virtual commissioning, as well as product improvement through feedback into product development.

__Dr.-Ing. Elisabeth Brandenburg__ studied Information and Media Technology (B.Sc.) at the Brandenburg Technical University Cottbus and Human Factors (M.Sc.) at the Technical University Berlin. After a scholarship at the DFG Research Training Group prometei (prospective human-technology interaction) with accompanying work as a guest scientist at the Fraunhofer Institute for Production Systems and Design Technology, she has been a research associate there since 2014. In the Virtual Product Creation, Department of Model-Based Development, she obtained the Dr.-Ing. degree and is head of the research and topic areas Workplace of the Future and Intuitive Interaction with Virtual Prototypes.

__Prof. Dr.-Ing. Rainer Stark,__ born in 1964, studied mechanical engineering at the Ruhr-University Bochum and Texas A & M University (USA). From 1989 to 1994 he was employed as a research assistant at the Chair of Design Technology/CAD of the Faculty of Technology at Saarland University. After obtaining the degree of Dr.-Ing. he joined Ford AG. His last position there was as Technical Manager of "Virtual Product Creation and Methods" at Ford Motor Company Europe. Since February 2008, he has been head of the Industrial Information Technology department at the TU Berlin and director of the Virtual Product Creation division of the Fraunhofer Institute for Production Systems and Design Technology.

https://www.ipk.fraunhofer.de/

References

[1] Global 360° Research Team at Frost & Sullivan. (September 2019). Global Mega Trends to 2030 – Futurecasting Key Themes that will Shape Our Future Lives. Frost &Sullivan, pp. 132-140.
[2] Stark, R., Fresemann, C. & Lindow, K. (2019, Issue 1, Volume 68). Development and operation of digital twins for technical systems and services. CIRP Annals, pp. 129-132.
[3] Wissenschaftliche Gesellschaft für Produktentwicklung. (Juli 12, 2020, 10:00). WiGeP-Positionspapier: Digitaler Zwilling. Retrieved from http://wigep.de/fileadmin/ ositions-_und_ Impulspapiere/Positionspapier_Digital_Twin_englisch.pdf
[4] Hoppe, Florian; Hartig, Jakob; Martin, Daniel; Staudter, Georg; Öztürk, Tugrul; Anderl, Reiner et al. (2020): Identification of lack of knowledge using analytical redundancy applied to structural dynamic systems.
[5] Biesinger, Florian; Meike, Davis; Kraß, Benedikt; Weyrich, Michael (2019): A digital twin for production planning based on cyber-physical systems: A Case Study for a Cyber-Physical System-Based Creation of a Digital Twin. In: Procedia CIRP 79, S. 355–360. DOI: 10.1016/j.procir.2019.02.087.
[6] Creditreform Berlin Brandenburg; Investitionsbank Berlin. (June 19, 2019). KMU-Report 2019 – Wirtschaftslage und Finanzierung. Berlin: Verband der Vereine Creditreform, pp. 15-17.
[7] Fraunhofer IPK. (Januar 23, 2020, 10:50). Leistungszentrum Digitale Vernetzung. Retrieved from https://www.digitale-vernetzung.org/
[8] Beckmann-Dobrev, B. (2019). Der Fertigungsarbeitsplatz der Zukunft. Produktionsumgebung von Morgen – ProMo. Futur 2nd ed. Fraunhofer IPK
[9] Geng, Z., & Bidanda, B. (March 2017). Review of reverse engineering systems – current state of the art. Virtual and physical prototyping, pp. 161-172.
[10] Buonamici, F., Carfagni, M., Furferi, R., Governi, L., Lapini, A., & Volpe, Y. (Volume 15. No. 3 2017). Reverse Engineering modeling methods and tools: a survey. Computer aided design & applications, pp. 443-464.
[11] Mönchinger, S., Schmidt, M., Dreßen, S., Wissmann, P., & Stark, R. (December 6, 2019). Automatized 3D-Scanning application for the virtualization of large components. Proceedings of the ASME 2019 Gas Turbine India Conference.