COMPOSITE TESTING 4.0 – A NEW APPROACH TOWARDS QUALITY ASSESSMENT USING COLLABORATIVE ROBOTICS AND MULTI SENSOR MEASUREMENT

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Abstract

Especially in the area of carbon composites, mostly for prototypes and small scale series an increasing demand for a fast and easy to use quality inspection systems is obvious. The new generations of collaborative robots have already found their way into the production industry. To determine the quality of a manufacturing process and to enhance the potential of CFRP parts, a holistic approach is required, which also helps to obtain a better understanding between simulation and production. The fiber orientation in CFRP parts can be crucial for structural component design in order to overcome simple “black metal” designs. Hence we present a mobile measurement unit based on a combination of a collaborative robot with various sensors. The combination of different data sets (resulting from different sensors) in a consolidated data model (e.g. 3D scan data and texture analysis) will allow the user to combine all relevant information in the same data set and thus have a full overview of the quality of his material. In summary, the presented combination of collaborative robots with optical testing methods will open new avenues in the domain of quality assurance.

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1. Introduction

Hand in hand with the industrial usage of carbon composite materials in small batch production as well as in series production, an increasing demand for fast an easy to use quality inspection systems is arising. Future manufacturing concepts are going to be more flexible and will focus on small batch series rather than mass production. Hence also systems for quality control have to take these trends into account. Carbon Fibre Reinforced Polymer (CFRP) parts have tremendous, however highly anisotropic properties (e.g. strength, stiffness, lightweight,…). Scratches can compromise the integrity of several layers, bore-holes in carbon compounds can cause so called push- and pull out phenomena. Furthermore any kind of machining on carbon parts can cause effects like delamination or fraying. Preforming processes can cause geometrical deviations which can affect the later usage of the part. Even more importantly, preforming processes such as braiding with yarns or draping of fabrics potentially have a strong effect on the fiber architecture of the part and thus on the mechanical properties. Contaminations on the surface might affect the subsequent joining of two parts, when glued. Any deviations in the measured properties thus allow conclusions to changes or trouble spots in the production process.

In the following we will outline, how the combination of collaborative and advanced robotics with different sensors will allow a highly flexible and still automated way to inspect the above listed phenomena and part properties.

2. Methods and Results

2.1 Robotics

2.1.1 Collaborative robotics for measurement and inspection

Robot based inspection and measurement of various properties like roughness and 3D geometry deviations or surface defects already exists on industrial robots for several years. However, industrial robots are highly dangerous, immobile and require enormous efforts on safety. Using the new generation of collaborative robots, all these disadvantages are obsolete, since the torque and momentum sensors as well as the high level controls of the robots (PL D, cat 3) offer the chance of "true" collaboration with the worker.

In **FIGURE 1** we show a collaborative robot in a possible working scenario, next to human workers.

Figure 1. Possible working scenarios using collaborative robots: a) tactile teaching of a robot path for automatic and intelligent rework. b) 3D scanning of a collaborative robot in a metrology laboratory

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2.1.2 Advanced robotics - workflow of a measurement task

When designing the system we focused on three key factors: The system has to be easy to use, it should offer a high repeatability and require minimized user input. Not only experienced metrologists should be capable of using the system, however everyone should achieve the same and reliable results when using the system. Therefore a minimum required user input is necessary, especially to obtain user acceptance in the production industry.

In **FIGURE 2** the workflow of the system (independent of the used sensor) is outlined. Due to the automatic generation of the robot path this is the workflow for various sensors (fiber direction, 3D geometry, surface bonding capabilities, …)

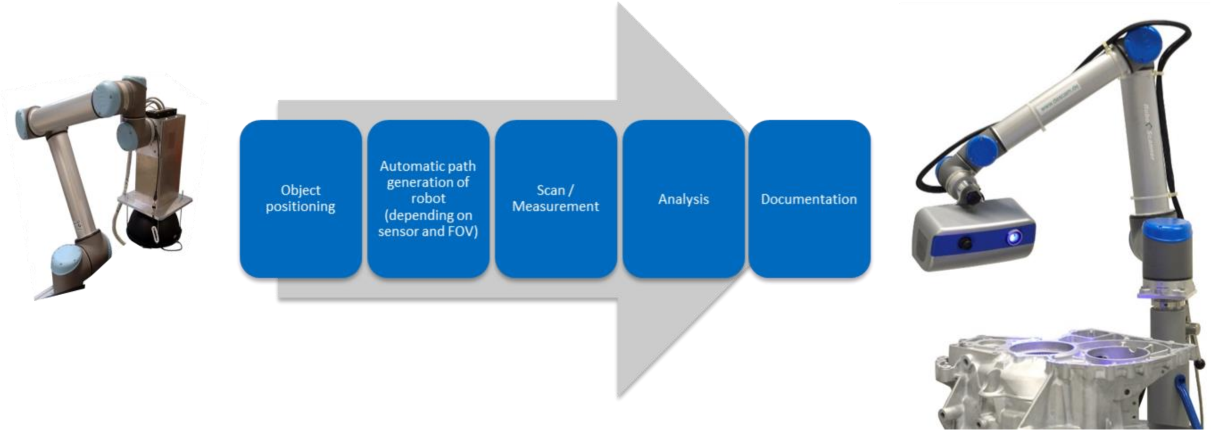

Figure 2. Workflow for a measurement task (left to right): The only active thing the user has to do is to import a reference geometry into the software. Based on that and the chosen sensor, the robot can generate its path fully automated. The scan/measurement is done automatically as is the analysis. All results can be stored automatically.

As stated above, one of the key issues is the robot path generation. The different sensors and measurement techniques pose different requirements on the robot path generation. When the robot guides the sensor to the respective positions on the surface of a sample, the typical characteristics of a sensor (field of view, working distance, viewing angle,..) as well as of the sample (curvature of the surface, roughness, ….) have to be taken into account. Respecting these criteria, we found a stable way to automatically create a robot path for a full scan/measurement of any kind of surface using different sensors. The only prerequisite therefore is the 3D geometry of the object – either as a CAD model, or as a 3D scan [2].

Different measurement techniques have different requirements on the positioning of the sensor, e.g. measuring the fiber direction of carbon composites only yields valid results if the sensor is orthogonal to the surface. A accurately scanned 3D geometry of a part using structured light projection requires an overlap between the different fields of view of the scanner. Inspecting the bonding capabilities of a surface by means of a wettability test needs the robot to be moved with a constant feed rate. All these issues have to be considered when scanning an object.

In the following section, different sensors which can be used to characterize various properties of an object are described.

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2.2 Sensor technologies for different sample properties

2.2.1 Measuring the 3D geometry

Especially for CFRP parts, the 3D geometry in combination with the fiber orientation is a critical property for the mechanical integrity of a part. During production of CFRP parts, forming and deforming of the initial flat – textile material can cause deviations from the actual target shape of the part, therefore 3D geometry measurements are essential for quality assessment. The combination of 3D geometry and fiber orientation can influence the design process of CFRP parts. In preliminary tests of the measurement systems, structured light projection showed the best results. Here, a structured light pattern is projected onto an object, while the camera records the images and reconstructs the 3D geometry based on triangulation. For automated 3D geometry measurement with a robotic system, the CAD model serves as a basis for the automatic path generation.
In **Figure 3** the system setup for 3D scanning, as well as the results for a target/actual comparison are presented.

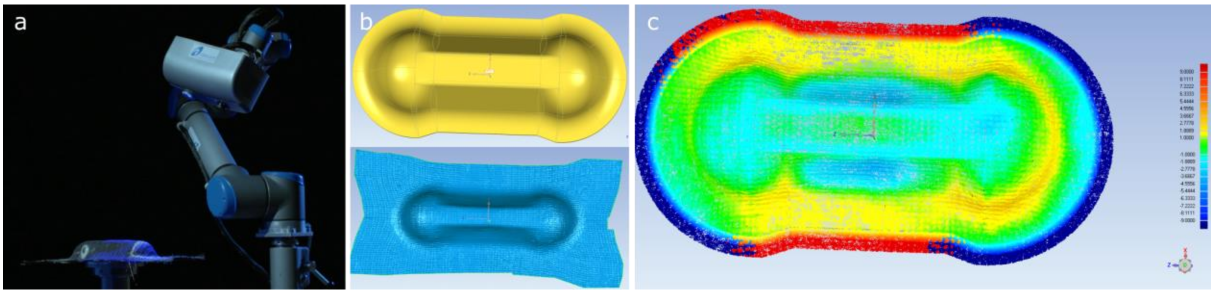

Figure 3. a) Autonomous and mobile structured light projection system combining a collaborative robot and a 3D scanning head b) CAD model (top) and scanned data (bottom) are compared c) false color results showing the deviations from the target shape

2.2.2 2D texture analysis

The texture of both dry fiber preforms and CFRP laminate surfaces can be analyzed to measure specific material and part properties. In order to allow for a complete investigation of geometrically complex surfaces, a 2D camera system is used which captures single images of the body. By robotically guiding the sensor over the surface, the position of each picture is linked to the part, so that the full surface texture can be reconstructed afterwards. Therefore, a path planning software to define the robot positions is used, which has been developed at the Institute of Aircraft Design in the collaborative ZIM project “3DMosaik”, funded by the German ZIM programme.
Partners of the project are Descam 3D Technologies GmbH in Munich (Germany), Faserinstitut Bremen e.V. (Germany) and the Institute of Aircraft Design in Stuttgart (Germany).

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FIGURE 4 shows a result of the surface and path planning algorithm. First, 3D scans are performed with structured light projection to receive the surface geometry. Then the algorithm defines single images with a limited size on the measured data, depending on the local curvature. The software finally calculates the corresponding robot coordinates of the sensor. All texture images are later displayed on the 3D scan as it can be seen in FIGURE 7.

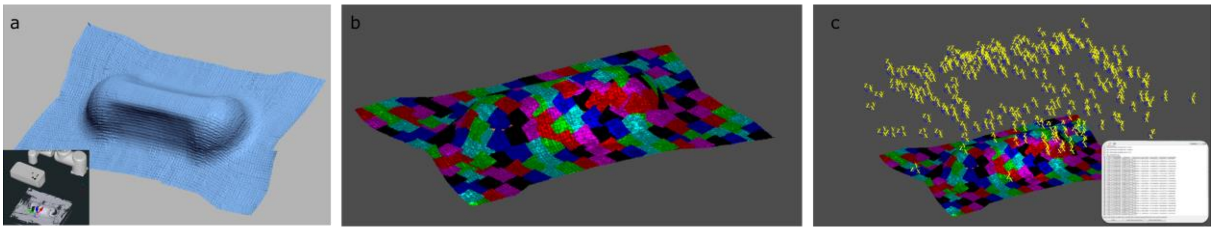

Figure 4. Automatic path generation: a) 3D geometry of the object serves as a basis for the robot path (either as CAD model or as scan data). b) 3D geometry showing the calculated fields of view of a specific sensor, c) as b) with the TCP points. The insert shows the automatically generated robot script.

In order to extract fiber architecture data from the 2D images, image processing algorithms are applied on the data, which allow for measuring fiber orientations, gaps or other defects.
Especially the direction of carbon fibers can be crucial for the structural integrity of the part. Hence, the inspection of the fiber directions pose an essential element in the chain of quality inspection.
The detection of the fiber orientation is achievable through different methods, which are described below. The measurement can e.g. be based on the polarisation of light. Therefore, the surface is illuminated by a homogeneous polarized light source. The reflected light waves show a different polarisation for different fibre-orientations. With the help of multiple pictures and by using a polarisation filter with different rotation angles, it is possible to measure the orientation of the fibers. By fitting the different results of measured light intensity to a sinus function, the fiber angles can be calculated. A second method for determining the fiber orientation is based on analysing 2D greyscale images based on gradient filtering. A gradient image is created, which serves as a basis for fiber direction determination via orientation histograms [1], [3]. In this case no polarision filter is needed for image acquisition. These sensors can be fully integrated into a robotic system as described in section 2.1. These methods are currently tested for stability and requirements on image quality and other aspects in the joint research project 3DMosaik.

In Figure 5, a prototype system with a sensor head is shown, which measures the fiber orientation. By using a collaborative robot, it is possible to check different geometries through multiple measurement phases.

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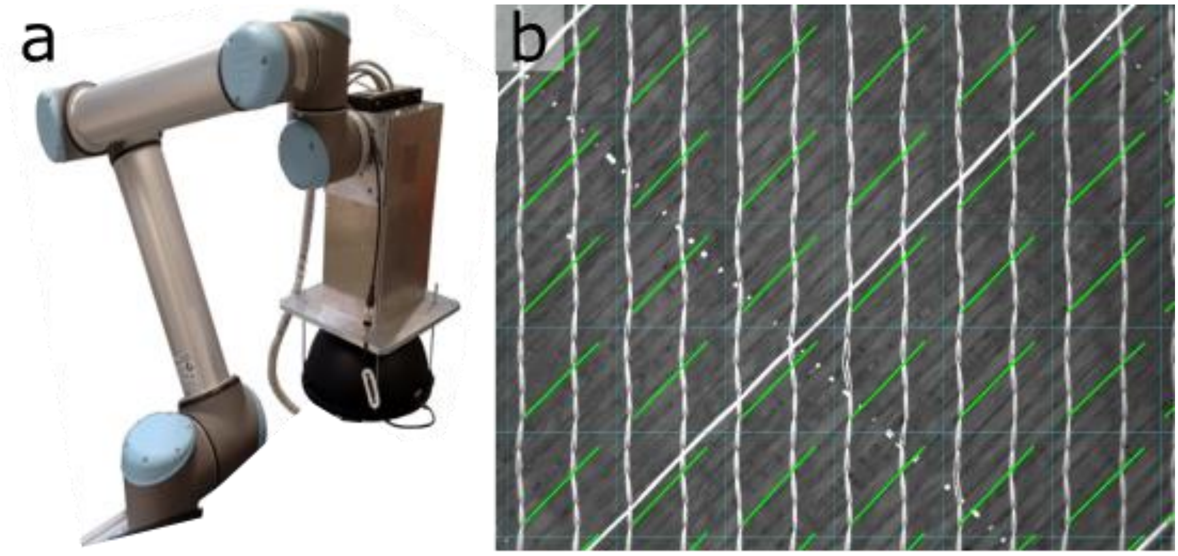

Figure 5. a) Fiber orientation sensor on collaborative robot b) reference sample with measured fiber orientation (gradient filter technique). For better visibility, the fiber orientations are highlighted by the green lines in the respective areas

2.2.3 Determining the bonding capabilities of a surface

The aerosol wetting test allows for monitoring the surface state through its wetting behaviour. A water droplet bonding with any surface will form a contact angle depending on the energy of both the surface and the fluid. The aerosol wetting test is based on this simple principle. By spraying thin water droplets on a surface and analysing their size and size distribution, an evaluation of the surface state can be achieved. An ultrasonic vaporizer produces a defined water aerosol and, depending on the surface energy of the substrate, a specific droplet pattern forms on the surface. The droplets are automatically detected by a camera system and displayed using an imaging software (see Figure 6).

This sensor technology is designed for “side-line” as well as for “in-line” process. It allows to check the quality of pre-treatment steps (picture left) and to detect any contamination left on the surface (picture right). After the application of the aerosol, the surface dries within seconds. Using ultra distilled water ensures a stainless evaporation of the droplets. Now the surface is ready for bonding.

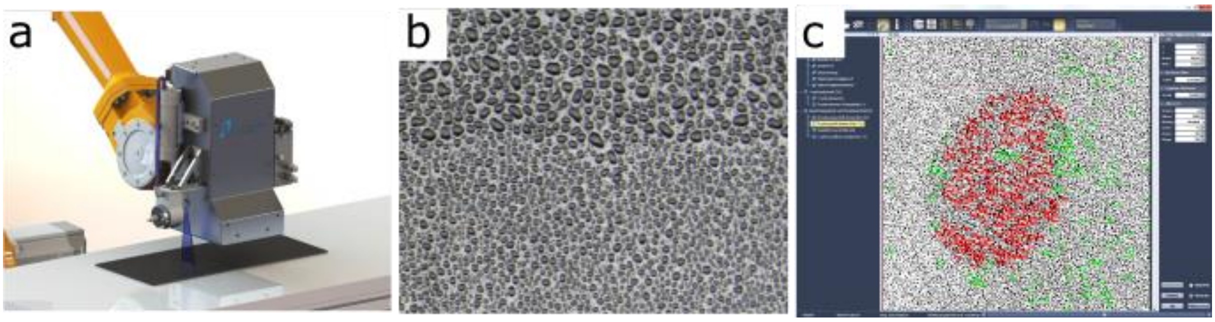

Figure 6 a) BoNDTinspect sensorhead on robot (simulation) b) water aerosol pattern on an interface between contaminated and non contaminated surface areas c) output format showing the contaminated area in red

The robot integration of this sensorhead on a collaborative robot system is still in progress. In addition to that, to fully consolidate the produced data sets with the data from 3D geometry

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measurement and fiber orientation measurement, additional research and development is necessary.

2.3 Consolidation of different data sets

Only the combination of different data sets (resulting from different sensors) in a consolidated data model (e.g. 3D scan data and fiber orientation) will allow the user to combine all relevant information in the same data set and thus have a full overview of the quality of the specimen. Only then, the full advantage of such a sensor independent measurement platform can be exploited.
Our system intends to provide two ways of analysis: A visual analysis, which can give immediate feedback to the worker in form of a 3D image, and concrete values, which can be stored for e.g. trend analysis or comparison between simulation an reality.

In Figure 7 it is shown how the 3D geometry model can be texturized with different 2D data sets, such as the fiber orientation. As it can be seen, these textures can display e.g. a photographic image (Figure 7 b) or a false colour scheme of the deviation of the properties (Figure 7 c) These visualization techniques give an immediate feedback to the operator on the quality of the respective specimen.

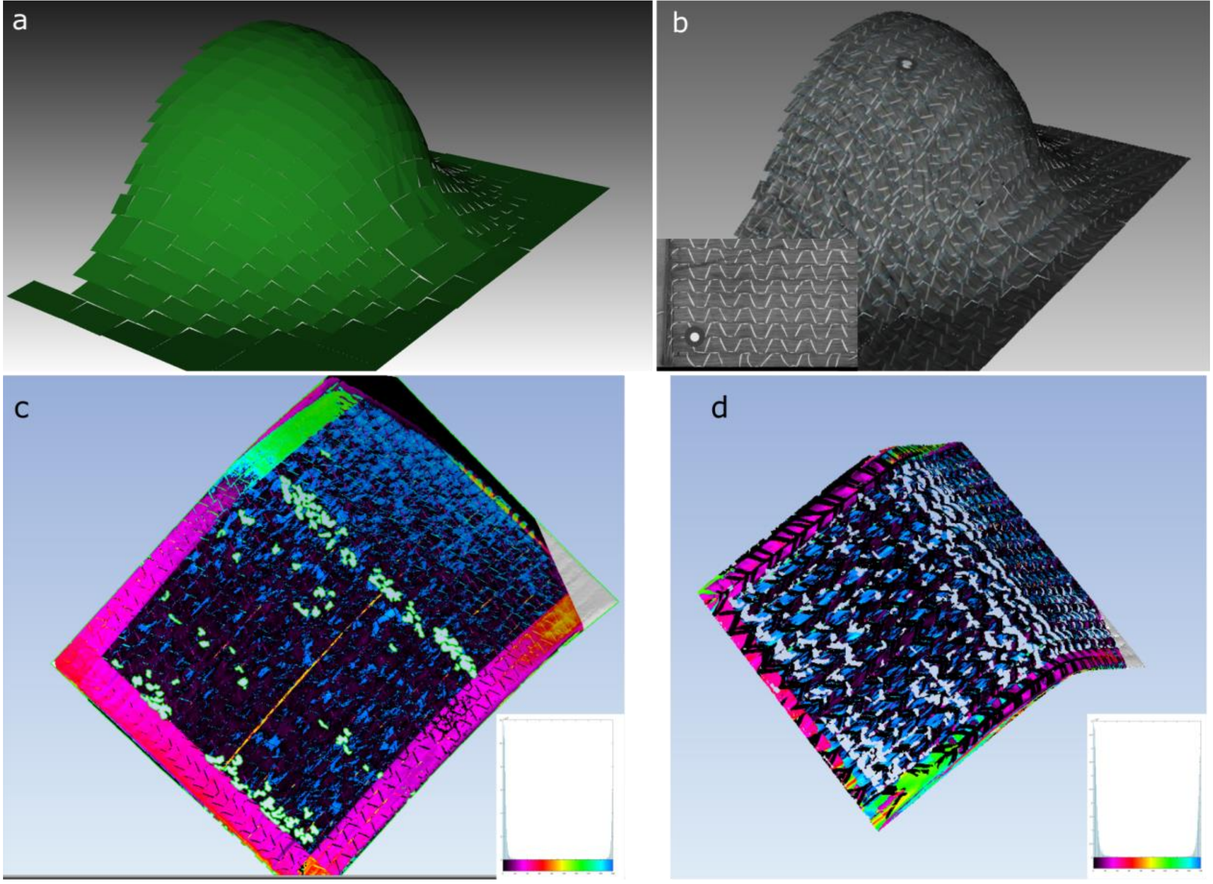

Figure 7 a) 3D geometry with small platelets indicating where the image is going to be projected, b) 3D geometry with real texture (the inset shows a close up). c) Reference sample (Non-crimp fabric with binder) showing the combination between 3D geometry and false colour fiber orientation d) triaxial braid sample with false colour mapping of fiber orientation

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3. Conclusion

In summary, the presented approach for a highly flexible, collaborative and sensor independent measurement unit will allow its users to get a fast and reliable feedback on the parts visual properties. The new generation of collaborative robots allows a flexible usage with a minimum need of safety requirements. The automatic path generation based on the parts geometry supersedes time consuming and difficult teaching efforts of the robots redundant and thus gives rise to financial benefits even for small batch series.

As a next step the prototype system will be further developed to a full product stage and the wettability test as described in section 2.2.3 will be integrated.

This unobstructed combination of autonomous moving robots with different sensor techniques combining 2D image analysis with 3D measurement techniques will allow the users to fully characterize a part from all different aspects within a single data set and thus give rise to a new form of quality inspection and development of CFRP parts.

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