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3D-Tomography: Exciting Possibilities Exceeding Conventional NDT

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ABSTRACT

Three dimensional X-ray Computer Tomography (3D-CT) enables to provide complete volume information of the test objects due to highly advanced cone beam tomography. The system is optimized to highest possible spatial resolution, presenting a spectrum of possibilities far beyond conventional procedures for non-destructive testing.

Conventional NDT techniques in most cases are limited to quality control in the sense of mere flaw detection. Now, 3D-CT offers new methods of analysis extending from sophisticated flaw detection in the complete object volume to geometrical measurements and reverse engineering.

New exciting possibilities have recently come up, opening a totally new field of application of industrial NDT.

Historic-cultural research has greatly profited from the 3D-CT as a valuable tool for gaining access to up to now unattained results. Among other topics the paper will present details on various applications in the fields of archaeology, palaeontology, restoration of works of art, as well as research on a variety of historical finds.

1 INTRODUCTION

New materials and improvements of conventional materials play in many industrial areas a key role for the design of innovative products. Development times have to be as short as possible. For this reason there is a growing demand for new inspection methods that allow a fast and non-destructive characterisation of materials. The complexity of industrial products is continuously increasing. At the same time also the safety requirements increase. For a rapid product development the inspection system needs to be able to characterise material properties in any section of components with complex inner structures. This task can often not be fulfilled with conventional NDT methods like ultrasonic or eddy current testing.

In this paper an innovative 3D tomography and radioscopy system is described that allows to perform variety of different inspection tasks with a single device. Examples from a wide range of different new materials will be given to demonstrate the potential of the NDT method in view of quality assurance and rapid product development.

The second part of the paper deals with a number of examples from applications in historic- cultural research. Among other topics the paper will present details on various applications in the fields of archaeology, palaeontology, restoration of works of art, as well as research on a variety of historical finds.

2 CONE BEAM X-RAY TOMOGRAPHIC SYSTEM RAYSCAN 200

The X-Ray tomographic systems which are in use in industry to date produce in most cases two dimensional sectional images. In such a system an X-ray fan from an X-ray source penetrates the object and the attenuation is measured by a linear detector. The object is rotated. During the rotation a set of one dimensional projections is measured and reconstructed. The result is a two dimensional image. To get a three dimensional image with such a conventional tomograph, the object has to be moved in the direction of the axis of rotation and several scans have to be performed. A stack of slices has to be mounted to get a three dimensional image.

Since the described procedure is very time consuming, our tomographic system RayScan allow the reconstruction of three dimensional structures with a single revolution of the object. A conical beam from an X-ray source penetrates the investigated object. The attenuated radiation is measured by a large area detector (Fig. 1). In order to irradiate the object from all sides, the X-ray source and the detector are either rotated around the object, or the object rotates in the X-ray cone. During rotation a set of projections is measured and stored. The set of projections is then used to reconstruct the 3D structure of the object.

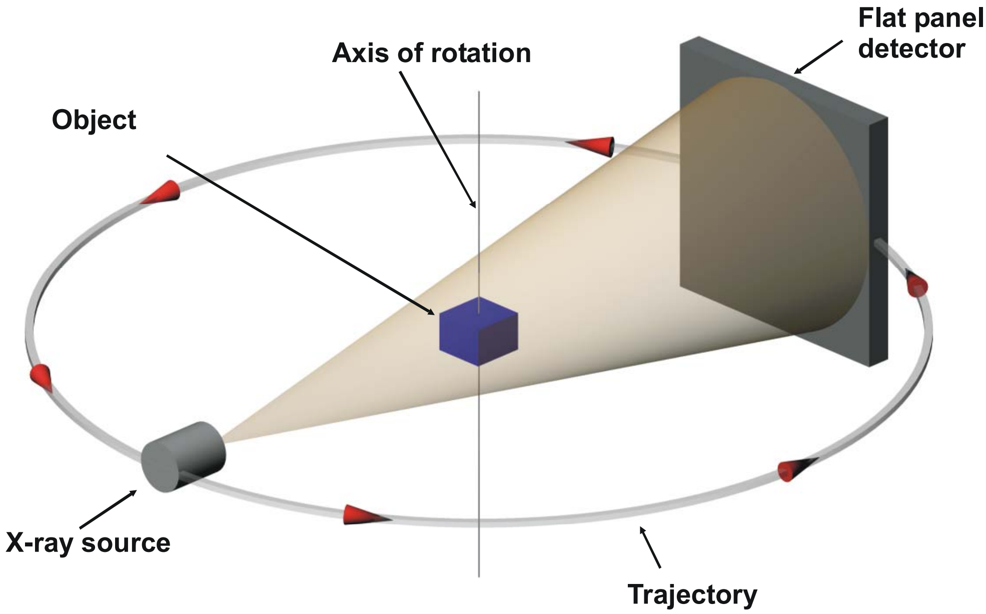

Fig. 1: Principle scheme of 3D cone-beam tomography

The advantage of cone beam tomography is besides the feature of fast volume scanning the fact that in cone beam tomography the high spatial resolution is obtained isotropically in all 3 directions. Therefore especially for bodies with complex inner structures 3D tomography is the appropriate inspection method. More details about the tomography system RayScan 200 are presented in another paper at this conference [1].

3 CONE BEAM TOMOGRAPHY APPLIED TO THE QUALITY CONTROL OF NEW MATERIALS

3D Computed Tomography has been applied to light metal castings many times. In this case the quality control is focused on two main aspects: Detection of flaws and dimensional measurements which includes the control of dimensions and the analysis of the deviation of the real geometry from the nominal geometry. Details about these applications are presented in [1] and [2].

In this paper we describe the application of RayScan 200 to quality control of new developed materials. By means of this investigations the materials, their composition and their behaviour is analysed and characterized. So the development of modern materials is accelerated. The production process can be monitored and the process parameters are optimised. In the following sections we give a short impression of the application to aluminium foams, ceramics and carbon fibre reinforced composites.

3.1 ALUMINIUM FOAM

Metal foams are of considerable interest to the automotive industry and other industries, where the special features of the material like high strength-to-weight ratio are of advantage. Compared to the light metal itself aluminium foam has a typical density of 17 %. Besides the weight saving the foam has a high stiffness, leading to applications in very light constructions. Because of its high strength it can be used in parts which are dedicated to the absorption of impact energy. In addition this material can be better recycled and has a much better heat and fire resistance compared to plastics.

Therefore this material has a great potential to be used if it can be produced with a defined quality of the foam which is related to pores with reproducable sizes and an isotropic behaviour. Since RayScan 200 generates isotropic 3D-data, it provides the ideal techniques for an inspection of the internal structure of the foam, for the location of density variations and for dimensional measurements. As an example of the 3D analysis of the foam a 3D visualization of a aluminium foam is presented in (Fig. 2). After the data have been taken, virtual 2D cuts can be applied in any orientation and direction of the volume. Examples of two virtual 2D cuts perpendicular to each other are shown in Fig. 3.

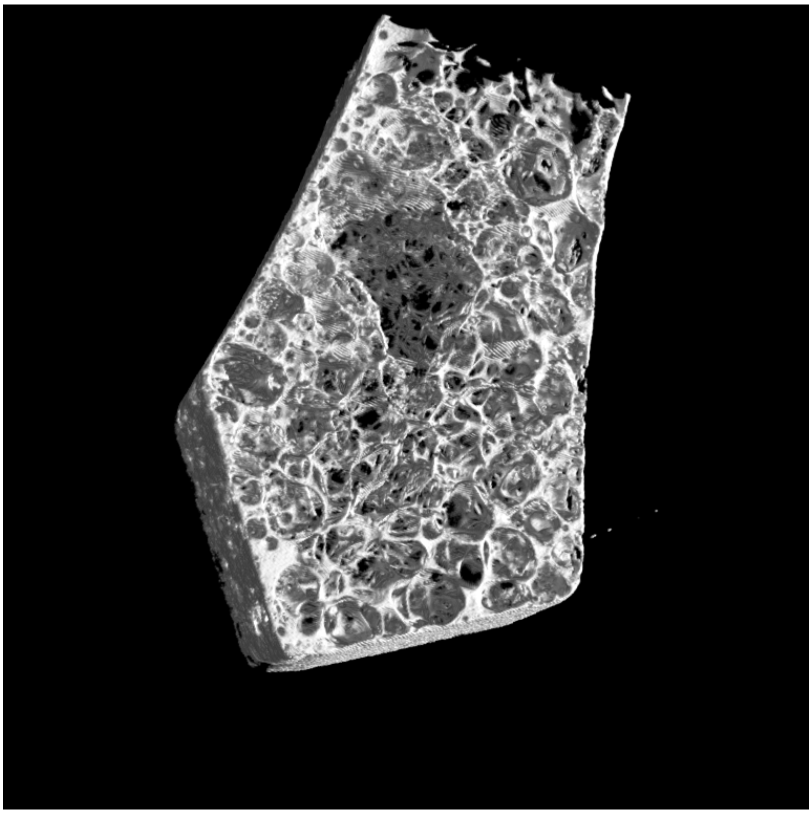

Fig. 2: 3D cone-beam tomography of a aluminium foam specimen

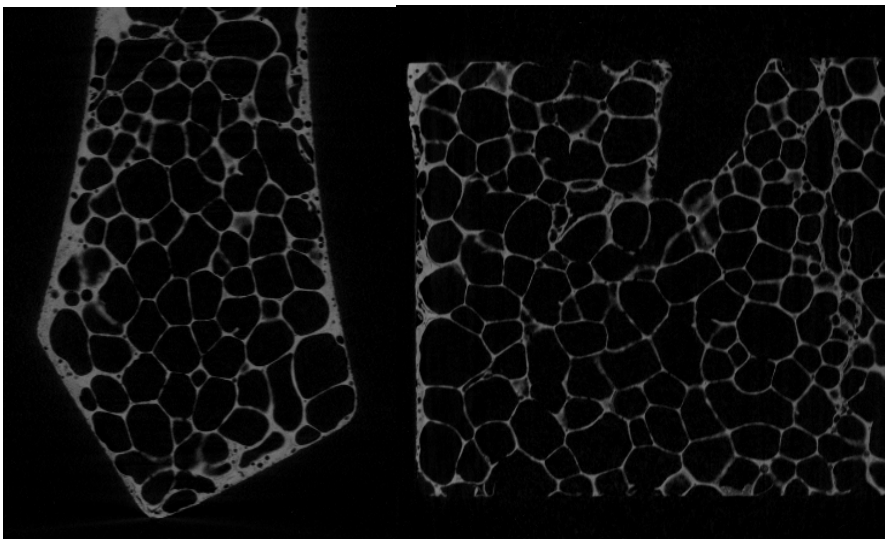

Fig. 3: Virtual 2D cuts through the 3D data of a aluminium foam specimen

3.2 CERAMICS

In connection with the development of new ceramics a systematic study of the material during different development stages and in relation to different production methods are important. 3D Tomography with its high spatial resolution is used for the detection of pores and the analysis of the 3D location of the pores. An example of a 3D visualization is given in Fig. 4.

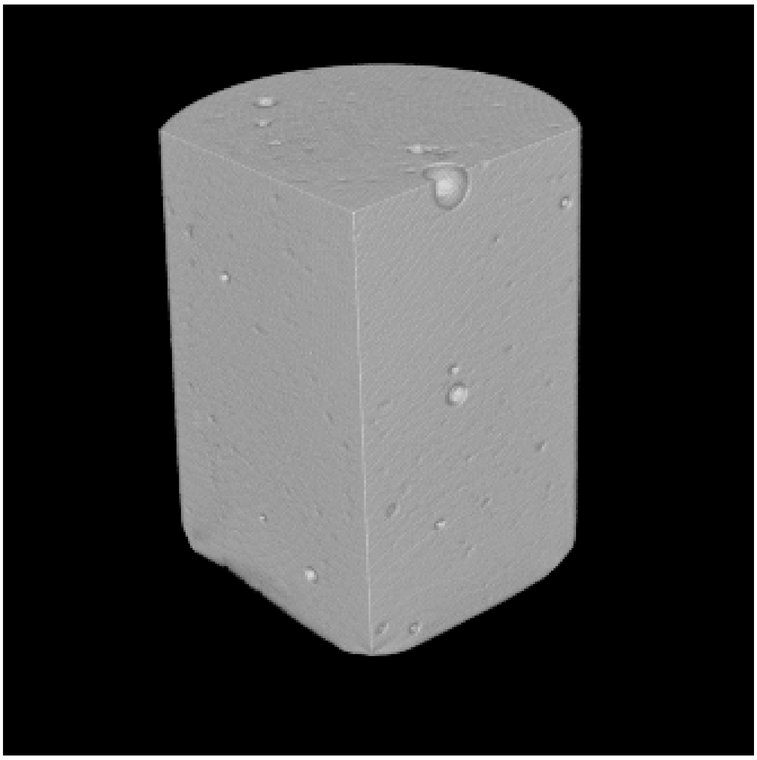

Fig. 4: Virtual 3D cuts through the 3D data of a small ceramic piece

The Ceramic object shown in Fig.4 has an outer diameter of only 2 mm. Therefore it has been checked by means of 3D Micro-Tomography. The 3D location of the pores of only a few microns is visible. Virtual 2D cuts through this data set visualize pores, tiny cracks and areas with density variations (Fig. 5).

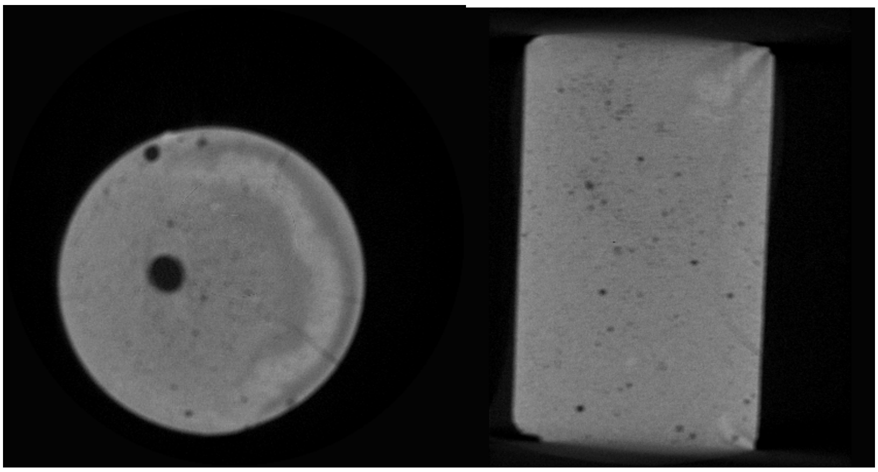

Fig. 5: Virtual 2D cuts through the 3D data of Fig. 4

3.3 CARBON FIBRE COMPOUND MATERIALS

Fibre reinforced composites are used in a variety of material combinations and many applications. By means of 3D Tomography of high spatial resolution the global structure can be visualized as well as density variations in the matrix material or in the fibre reinforcement. With other NDT techniques it is rather difficult or even impossible to detect delaminations or a lack of glue in joints. Both can be detected, visualized and analysed by 3D-CT. As an example we investigated the glue joints of carbon fibre reinforced compound materials, which are used as structure elements. Both in the 3D-Data as in the virtual 2D cuts the difference between perfect glue joints and a serious lack of glue is clearly visible (Fig. 6). In addition delaminations are clearly visible.

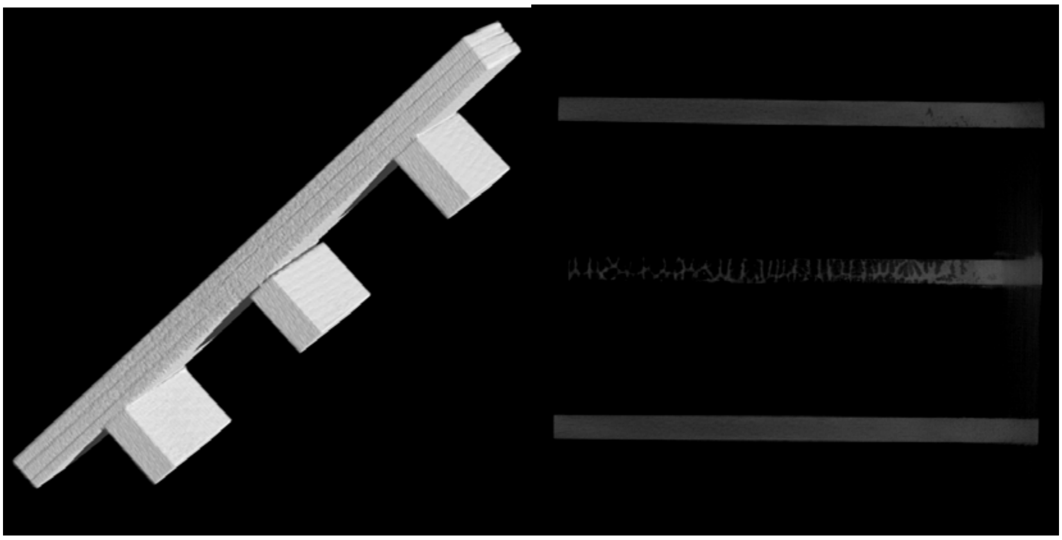

Fig. 6: 3D data and virtual 2D cut through the glue plane

4 APPLICATION OF 3D – TOMOGRAPHY TO RESEARCH AND CULTURE

Due to the powerful analysis methods which are opened by 3D – CT and the very high image quality achieved with RayScan 200, we have been approached by a wide variety of scientists from very different research subjects. In this chapter we will briefly describe a few of this applications which some times seem to be a little exotic from the viewpoint of conventional NDT.

4.1 CONSERVATION OF WOODEN ARTWORK

RayScan 200 was used to visualise the density of different wood specimen in the framework of a systematic study of different conservation materials and different methods of injection of these artificial raisin substances. Fig 7 shows a stack of wooden blocks with different raisin injections, which are mounted to the rotating table of RayScan 200.

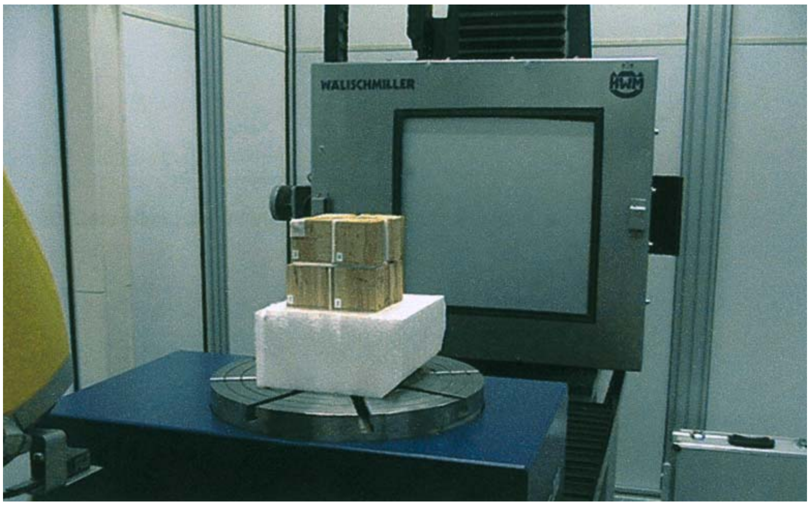

Fig. 7: Wooden specimen in front of the detector of RayScan 200

The aim of this systematic test series was to define an optimum combination of artificial raisin and application procedure to wooden artwork of comparable wood quality. After the best combination has been found it has been applied to a real artwork, which already has been considerably damaged by insects (Fig 8).

Fig. 8: Wooden artwork from about 1520 with a lot of damages caused by insects

The success of the application is demonstrated by the comparison of CT images taken before and after the application of the artificial raisin (Fig 9). The higher density due to the conservation substance is clearly visible in the right part of the figure. For further details of this work refer to the original publication [3].

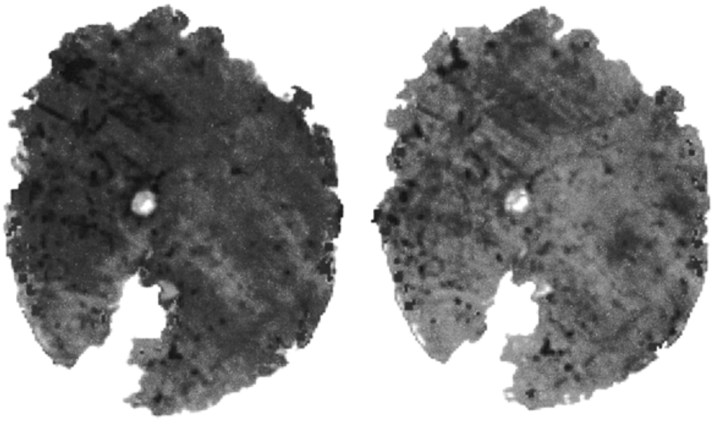

Fig. 9 : 2D- CT Images of the artwork from Fig. 8 before (left) and after conservation (right)

4.2 PALAEONTOLOGICAL INVESTIGATIONS OF BONES

For the purpose of palaeontological studies it is interesting to analyse and compare the internal structure of the bones of findings with different ages in the framework of evolution. The scientists try to find by this comparison correlations between the age of the finding, the evolutionary status and the density of the internal structures of the bones. For this kind of applications the very high spatial resolution provided by RayScan200 is made use of. An example of a very small bone and the 3D- CT image is given in figure 10. For further details refer to [4].

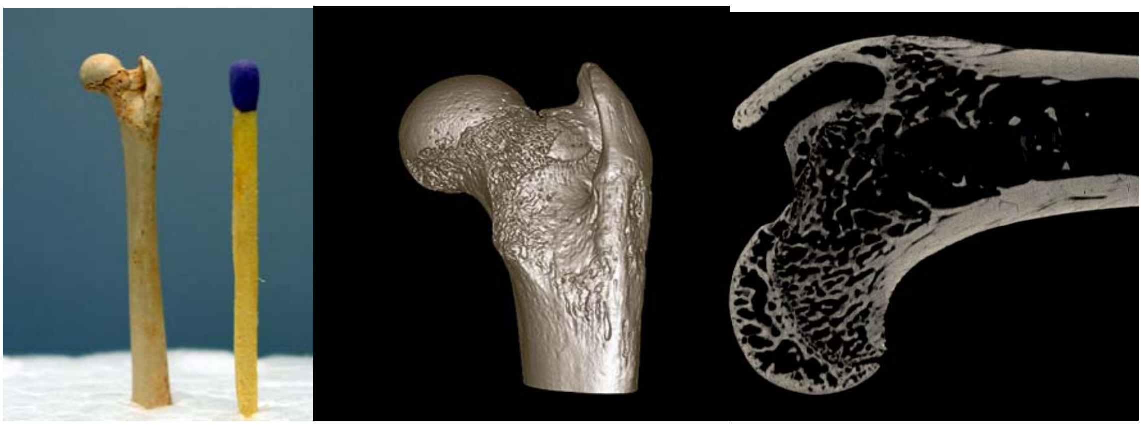

Fig. 10 : Photo (left), 3D-CT image (center) and 2D cut of the 3D-CT data (right) of a small bone.

4.3 REPRODUCTION OF AN PRAEHISTORIC ARTWORK

A 32000 year old artwork, said to be the oldest artwork showing a mixture of animal and man, has been investigated. Originally it has been cut out of a tooth of a young mammoth (albony) during an epoch called Aurignacien. The original piece has been found in Southern Germany in 1931, but it was broken into some hundreds of parts. In careful work it has been reconstructed and stored in the museum of Ulm (Germany)[5].

Fig. 11 : Photo (left) and 2D cuts of the 3D-CT data (centre and right) of the 32000 year old lion man.

Now the museum wanted to check the quality of the reconstruction work by means of advanced 3D Tomography. The CT images showed the original components as well as a stick made from plexiglass which has been inserted for stabilization of the object. Also some joint material could be made visible. But the most important information was the check of the nervous channel of the original tooth material. It could be shown that the channel passed straight through the object without deviations. By this it could be proven, that the reconstruction has been done perfectly and the outer form looks like the one produced 32000 years ago (Fig 11).

The second motivation of the investigation by Computed Tomography was the aim to create a copy by a contactless method. Conventional methods of copying artworks should be avoided, because of the risk of damages to the surface of the lion-man. Therefore the 3D-CT data have been converted to STL data. By means of stereo-lithography procedure a 3D model and finally copies of this praehistoric artwork have been produced.

5 CONCLUSIONS

The cone beam tomographic system RayScan 200 was shown to be a versatile tool for quality control in view of a rapid development of new products with new materials. The system allows a fast tomographic volume scanning as well as a high spatial resolution in all 3 directions. With a single NDT tool and a single measurement, defects in complex bodies can be detected and analyzed regarding their 3D shape, orientation and position.

Dimensional measurements of outer and inner structures can be performed to verify the geometry of parts. Therefore, the system gives new opportunities to rapidly optimise products and materials as well as production processes aiming at the minimization of defects and deviations from the nominal geometry.

Due to the unique feature of RayScan it could be used for a variety of exciting research applications, which are far beyond conventional NDT.

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