RoboCT – Application for in-situ Inspection of Join Technologies of large scale Objects

Wolfgang HOLUB 1, Franziska BRUNNER 1, Tobias SCHÖN 1
1 Fraunhofer Development Center X-ray Technology EZRT, Fürth, Germany
wolfgang.holub@iis.fraunhofer.de

Abstract. In sophisticated mechanical engineering like e.g. automobile industry, the reliability of joints like rivets, screws or adhesive bonding is usually being examined by regularly repeated destructive testing of these manufactured parts. At full scale, this implies disassembling whole car bodies so far that e.g. all adhesive bondings are being forcibly opened so that the geometry of these joints can be assessed.

Whilst X-ray CT is one established means of NDT applied to cutout specimens in the laboratories of such manufacturers, it is only beginning to become available to full scale objects since few years.

Over more than one decade, EZRT has developed the technology of RoboCT - the application of cooperating industrial robots as large and highly flexible manipulation system for the X-ray components. In 2018, we have taken into operation the very first such system in the field in BMW’s prototype plant. This system of four cooperating robots is designed to address large automobile components, whole car bodies or even fully assembled cars and shall help to reduce the time to market of new models.

In this contribution, we introduce the technology and its first implementation in production environment. We demonstrate the exemplary application of RoboCT to different join technologies.

Introduction

X-ray radioscopy and especially computed tomography (CT) are well established means of NDT in laboratories worldwide and also in some production lines for smaller objects with the necessity for demanding production monitoring. Nonetheless, there is a wide field of production scenarios that have not yet been suitable for monitoring by CT. This is mostly due to the size and geometry of the respective objects, which can hardly be handled by available X-ray equipment. Join connections in car bodies belong to the most prominent examples of such applications. Join connections like bondings, screws, rivets or weldings are being examined by X-ray NDT in the laboratory – but only within small cutouts that fit within such laboratory scale CT systems. RoboCT shall bring computed tomography to those large objects – in the laboratory and also in production.
1. RoboCT Technology

Laboratory CT usually depends on ambitious mechanical engineering to provide the geometric precision necessary for the algorithmic reconstruction of 3-D CT images from a series of 2-D radioscopies. Those designs do often rely on bases of granite to provide highest geometric and temperature stability. Consequently, classic CT systems are very limited to their possible dimensions and also to the trajectories, i.e. the kinds of acquisition procedures that they can perform.

EZRT has spent the past decade on the idea to replace highly precise manipulation systems by rather inaccurate industrial robots. On the one hand motivated by the immediate increase in work space (typical industrial robots reach up to more than 3 m, each) and the extremely high flexibility to move to any possible pose (i.e. 6-D position and orientation) or along arbitrary trajectories, on the other hand.

1.1 General System Setup

In general, we speak of RoboCT, i.e. robot based computed tomography, when at least one pair of cooperating industrial robots is being applied to carry X-ray source and detector, with hardly any limit to additional robots for more than one source or detector, object manipulation or complementary modalities like e.g. photography, stereography, thermography or ultrasonics.

![RoboCT system at BMW’s prototype plant](image)

*Fig. 1. RoboCT system at BMW’s prototype plant, robots carrying X-ray sources rear left and front right, robots carrying X-ray detectors and / or optical 3-D scanner front left and rear right, lifting table in the center*

The possible couples are then being used to prescribe different trajectories for 2-D or 3-D inspection along or around some object or region of interest (ROI). The possibilities reach from conventional circular trajectories – freely positioned and oriented within the work space...
of the cell – to completely arbitrary trajectories without any restriction to regular geometric paths.

The precision of industrial robots does only reach in the magnitude of ½ mm (average absolute euclidean positioning error in space) for the models with highest accuracy. Since this does not suffice for the application of CT with resolutions of some tens of Microns, the key enabling technology is the developed geometric calibration process that delivers the absolute position of X-ray source and detector in 6-D space – even with rather inaccurate manipulation hardware.

Resulting acquisitions are then being reconstructed to 3-D CT images by means of EZRT firefly reconstruction and correction suite with FBP reconstruction for quasi-regular circular trajectories and with SART reconstruction for laminographic or arbitrary trajectories.

1.2 RoboCT at BMW’s Prototype Plant

As result of the past research, we achieved to reach the necessary technology readiness level to implement the first laboratory RoboCT cell with BMW at their prototype plant in 2018. There, the system is helping designers and engineers to speed up ITO time – i.e. idea-to-offer time, the time needed to establish stable production processes of new models before they can be released to the market. That system consists of four Kuka Quantec extra KR90 R3100 HA robots on two linear axis, left and right of a lifting table for the objects like e.g. car bodies or fully assembled cars. The robots carry two Comet VarioFocus X-ray sources XRS-225VF (225 kV, adjustable focal spot size down to 250 µm) one Varex XRD3025 detector (300 mm · 250 mm, 100 µm pixel pitch) and one Perkin Elmer XRD 1621 (409.6 mm squared, 200 µm pixel pitch) and one Gocator optical 3-D sensor. The robots can cooperate in up to four different pairs – on either side of the object table or opposite to each other. (see Figure 1)

![Fig. 2. Application example of one pair of cooperating robots positioning X-ray source and detector at one car’s A-pillar](image-url)
After several experimental installations, both in aerospace industry and in the laboratory, this is EZRT’s first installed productive system in the field in automotive industry. At BMW Group it is being applied for different questions on large components, car bodies or even fully assembled cars that cannot be addressed with their regular CT systems. Situated in their prototype plant, its main aim is to accompany design and production of pilot-series vehicles in order to speed up ITO (idea-to-offer) times for new car models. The cell geometry is designed so that the system fits BMW’s largest models like the Rolls Royce Phantom with 6 m length. It shall enable accessing most ROIs – even of fully assembled cars, like e.g. the A-pillar of a BMW i8 Roadster (see Figure 2).

1.3 Research Setup at EZRT

RoboCT research and development at EZRT had started with some small Stäubli RX90B robots with which we also executed parts of the experimental basis for the application of Micro-CT on large automotive components [1][2][3]. In 2017, we upgraded to a system of two Kuka KR90 robots. This system has been applied for a full-scale feasibility study as R&D basis for BMW’s installation [4]. (see Figure 3)

![Fig. 3. RoboCT research setup at EZRT 2017](image)

Today, we work with a setup consisting of the two Kuka KR90 robots on 6 m linear axes, each in a cabin with 10 m · 8 m · 4 m (length, width, height) working space. (see Figure 4) We apply one Varex XRD 3025 detector and a prototype source from Comet which shall come to the market, in near future. This MesoFocus source is Comet’s development of a closed source towards the focal spot sizes necessary for Micro-CT applications. The 225kV source has an adjustable focal spot of 50 µm to 200 µm with 1 W/µm power [5]. Apart from the higher achievable resolution with 50 µm instead of 250 µm focal spot size (compared to the VarioFocus tube recently applied), this tube gives us better accessibility in RoboCT.
applications due to the fact that it allows acquisitions at magnification M=2 where the
detector may be equally far away from the object ROI as the source.

Fig. 4. RoboCT Research Setup at EZRT 2019
with one pair of robots on linear axes at an automobile on a lift table

2. RoboCT Application on Join Connections

2.1 State of the Art Join Inspection

In automotive industry, the quality of joints e.g. in the car body is regularly being
destructively tested on control samples. Therefore, the car body is being completely
disassembled in order to perform e.g. micrographic analysis of rivets and visual inspection
of adhesive bondings.
This kind of destructive testing costs both time and money and requires long delay until the
results become available which leads to long reaction times in case of some process failure.

2.2 Join Inspection by RoboCT

One of the most relevant applications for automotive industry has been to find a solution to
assist the inspection of joints in the car body manufacturing by means of X-ray NDT.
Together with BMW, we investigated the application of RoboCT on car body parts [4]. As a
result, BMW decided to implement the first RoboCT system in their prototype plant. Not
only, but also for the application at join connections on the whole automobile. Figure 5 shows
results from BMW’s publication [6] on their applications of RoboCT. The shape and
geometric features of the punch rivet can be visualized and measured and the adhesive
bonding between layers in the aluminium car body can easily be visualized.
Figure 6 shows the CT image of one row of different joints within a test specimen of three-dimensionally shaped aluminium sheets of approximately 1 m · 1 m · 40 cm. The shape and deformation geometry both of aluminium and steel pop rivets can easily be seen, as can the insertion of the self-piercing screw. The orthogonal slice in between the sheets of aluminium shows the adhesive bonding in between and allows to identify pores and the flow front of the glue.

3. Summary and Outlook

RoboCT proves to more and more become a solution to perform Micro-CT on very large objects that have not yet been accessible by any other CT setup.

For EZRT, RoboCT builds one of the first steps towards cognitive sensor systems, i.e. smart monitoring systems that do intelligently apply and parametrize their multimodal sensors. RoboCT represents a very powerful, yet difficult to apply technology due to its high dimensional parameter space – especially when it comes to completely arbitrary acquisition trajectories. Smart, AI based acquisition planning will help this technology to become one first cognitive sensor that will assist the user to find the most suitable parameter set for a given task. With RoboCT, the next step will consist of the automatic acquisition planning on safe, collision-free trajectories, followed by optimized acquisitions to provide best possible CT image quality at the given accessibility.

In the future, RoboCT shall become part of a cognitive sensor system – a blackbox of multiple modalities, intelligently combining those either for best image quality or most efficient results given a concrete task with prior information on shape and material of an object and on the monitoring task.
Fig. 6. RoboCT acquisition of sample specimen: one row of steel and aluminium pop rivets, a self-piercing screw and adhesive bonding joining sheets of aluminium

References

[8] Holub, Wolfgang et al.: “RoboCT and XXL-CT – X-ray imaging for non-destructive testing of large and complex car components up to the whole car body”, AEE Congress – Automotive Engineering Expo 2019