Robotic X-ray inspection system

Model case: small aircraft inspection

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Introduction: X-rays & robots

Radalytica s.r.o. is developing an X-ray imaging system that combines cutting edge X-ray imaging detectors[1] with the flexibility of collaborative robots aiming to provide customers with a system applicable in a wide range of cases starting from biological research to airspace industry.

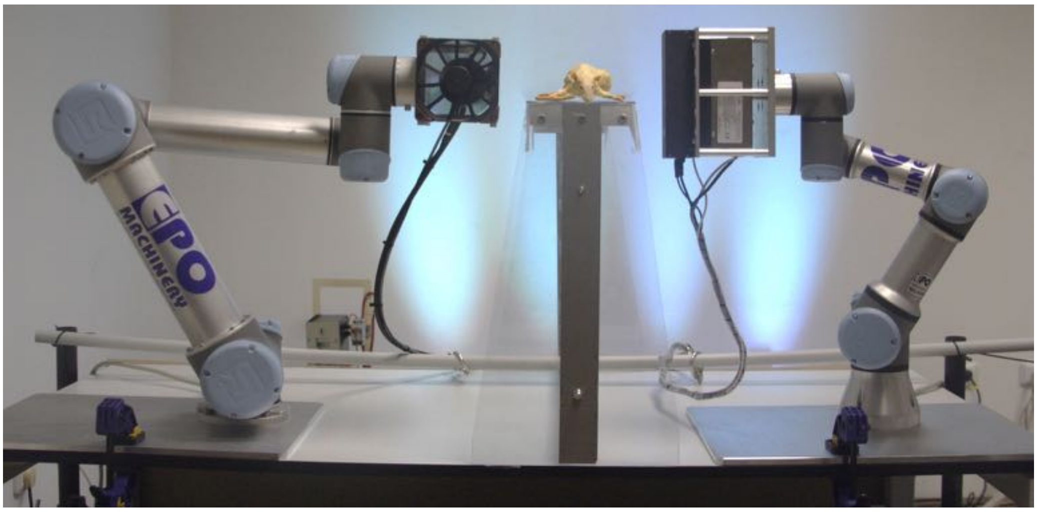

Fig.1 **A pair of robotic arms holding X-ray tube (left robot) and X-ray imaging detector (right robot). The imaging test was performed in this case for small animal imaging for pre-clinical research of new drugs and cancer treatment techniques.**

Our first test setup is shown in Fig.1. It utilizes two Universal Robot (UR) robotic arms. The left arm holds an X-ray tube (X-ray source). The X-rays are passing through the sample. The sample casts shadow in the X-ray beam. The shadow is imaged by the imaging detector which is held by the second arm. The imaging principle is shown in Fig.2 and an example of final X-ray image is in Fig.3.

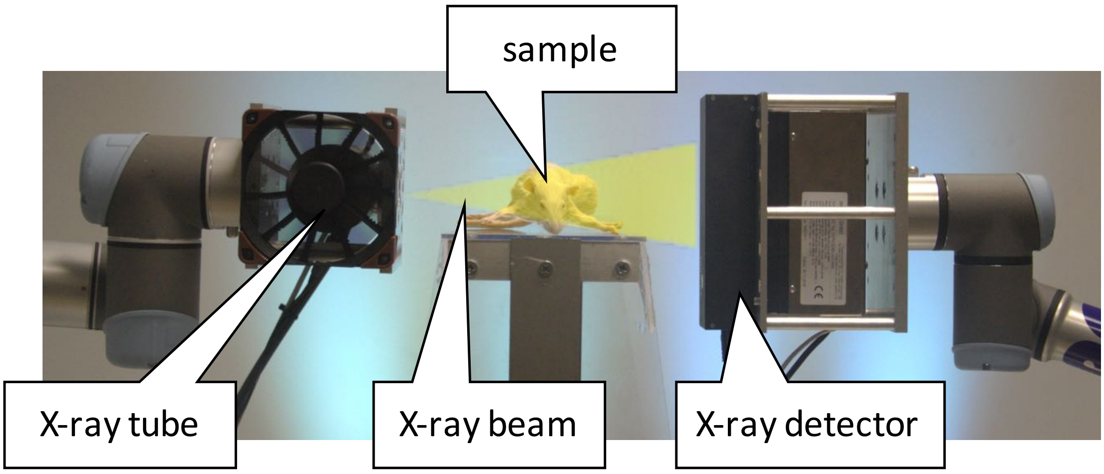

Fig.2 **Detail of the X-ray imaging setup: X-rays generated in the X-ray tube are passing through the sample and are detected by the imaging detector. The intensity of X-rays is changed by the sample to different levels revealing the internal sample structure.**

[1] These devices are based on Medipix/Timepix technology developed at CERN using know-how from particle physics experiments. These devices find a wide range of use starting from X-ray imaging to radiation monitoring in space.

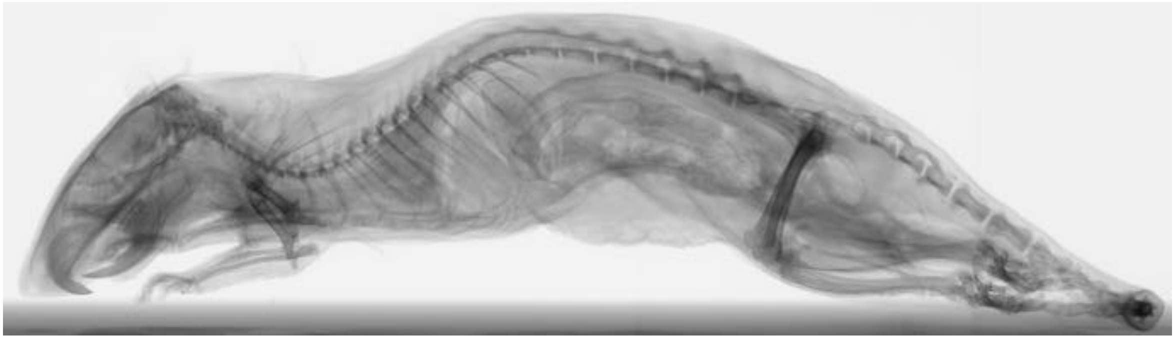

Fig.3 X-ray image of the animal measured in the setup Fig.2.

Why robots for X-ray imaging?

Both the X-ray tube and the detector are in classical X-ray imaging systems fixed or can move only in a limited range of directions (up/down/left/right). There is typically no flexibility to rotate about an arbitrary axis, i.e. look at the sample from different angles. Common is only rotation about one axis for Computed Tomography. It is also not easy or possible at all to automatically inspect small parts of larger structures. An example could be welds of A, B and C pillars of a car body that are important for structural strength yet hard to inspect with classical devices in a production line.

An example of a common X-ray imaging system is in Fig.4. It allows linear moves of the X-ray tube and detector which limits the imaging flexibility. As mentioned above, it is not possible to inspect the sample from different angles. Contrary to the classical X-ray system, the robotic one allows nearly arbitrary flexibility of view angles. This is shown in Fig.5 where a high-performance titanium bike frame was inspected. The resulting X-ray image with identified defect is in Fig.6

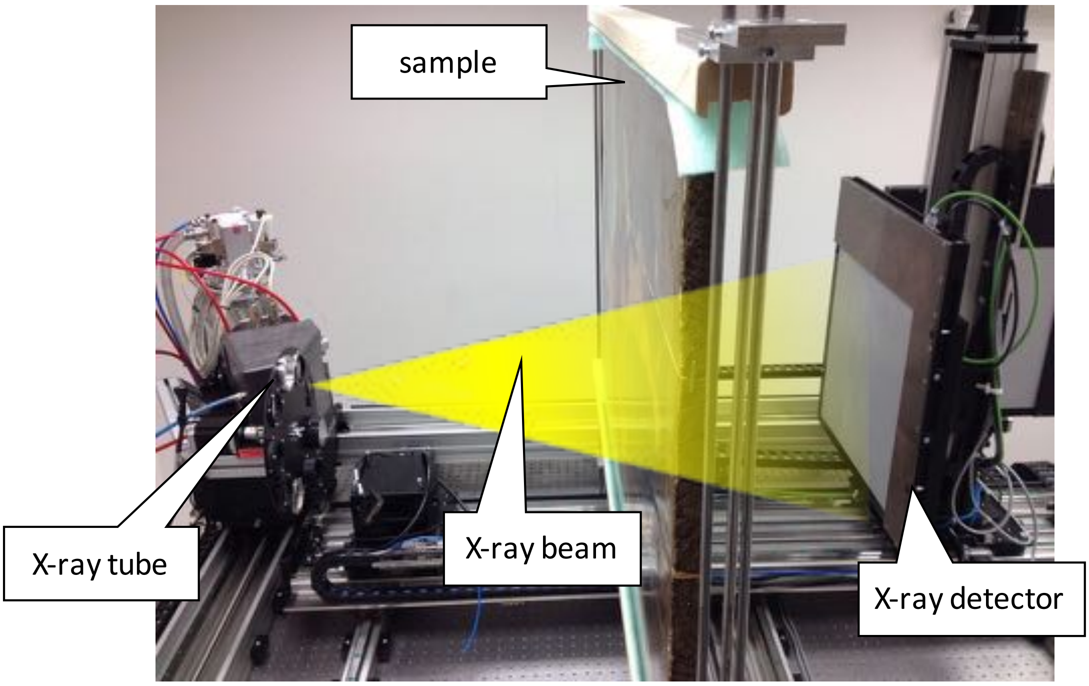

Fig.4 A typical X-ray imaging setup where the X-ray tube and detector can move only linearly => very reduced range of imaging angles limiting the possibility to visualize some defects or internal sample structures.

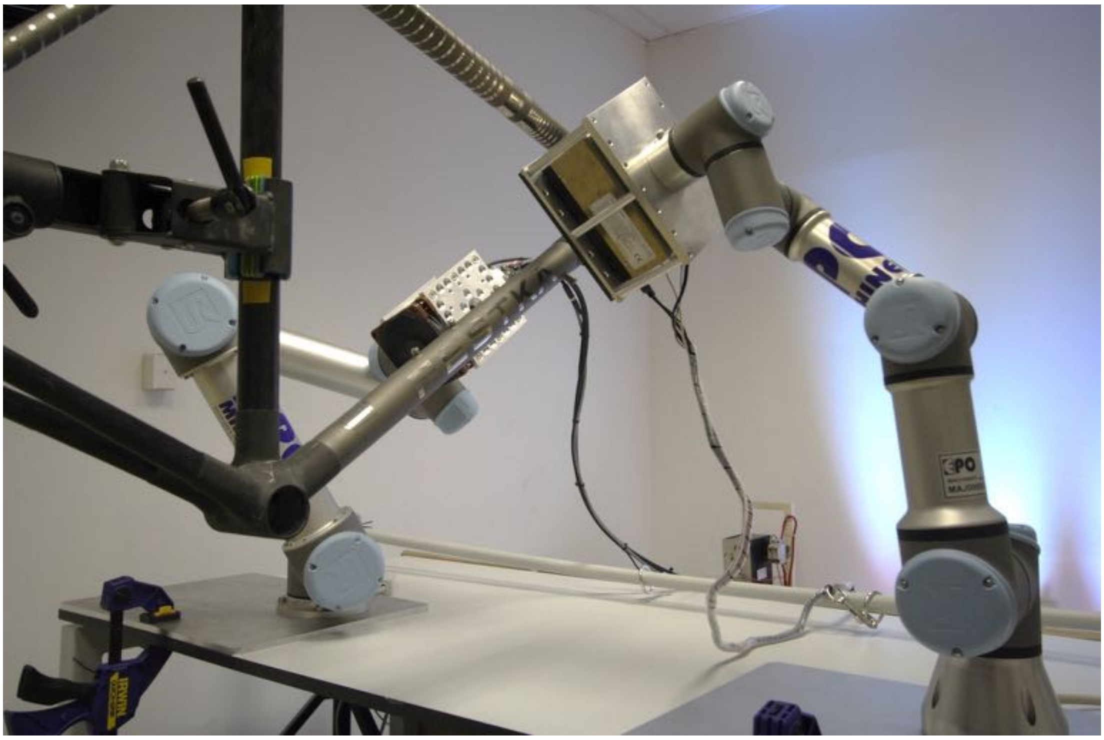

Fig.5 **Robots inspecting a high-performance bike frame for defects. The bike frame is a typical sample which takes advantage of robotic system – it is necessary to inspect only relatively small areas that are parts of a large structure.**

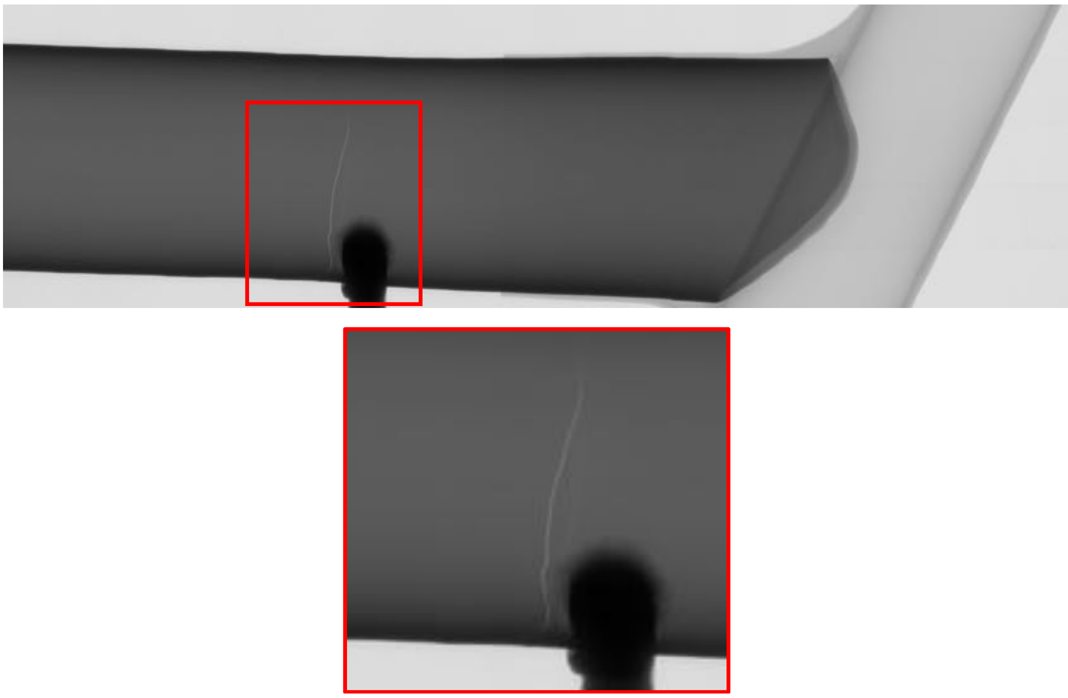

Fig.6 **Final X-ray image of the scanned frame and detail of the identified crack in the titanium pipe.**

The robotic system prototype in operation could be seen under these links:

- High-performance bike frame (https://youtu.be/ib_PPYvcIZE)
- Small animal scan (https://youtu.be/MQDFijNW-dg)

Robots further allow using 3D imaging techniques such as computed tomography or tomosynthesis. These are methods commonly used in X-ray imaging, however, with limited applicability on large, complex shapes. **Robots can do this all!**

Integration of X-ray imaging with UR software & hardware

The acquisition of X-ray images has to be synchronized with movement of both robots. The X-ray imaging detectors are producing large amounts of data requiring sufficiently powerful computer at the same time. These tasks is fulfilled by a master computer that is connected via TCP/IP or Profinet to robot control units. However, the full control via external computer is mostly used in case of regular repetitive inspection where the robots will be repeating already programmed paths.

Programming phase of robots as well as manual inspection using X-rays, i.e. when operator controls movement of robots directly to "look" into specific parts of the sample, takes advantage of integration of the detector and robot control into Universal Robot's PolyScope software. PolyScope is extended by a tab allowing control of the X-ray tube and X-ray imaging detector. A preview of possible implementation is in Fig.7.

The software allows manual movement of either robot holding the X-ray tube or detector. The second robot automatically follows movement of the first one. The operator can set this way location(s) where an X-ray image is to be taken. Programming of the robot is done this way too. I.e. operator is able to manually set points where images should be taken or define start/end points of X-ray imaging scans. The software also allows defining that tomosythesis or computer tomography (i.e. measuring 3D data) of a selected area should be measured. The videos mentioned earlier in this document show how the device will perform these scans.

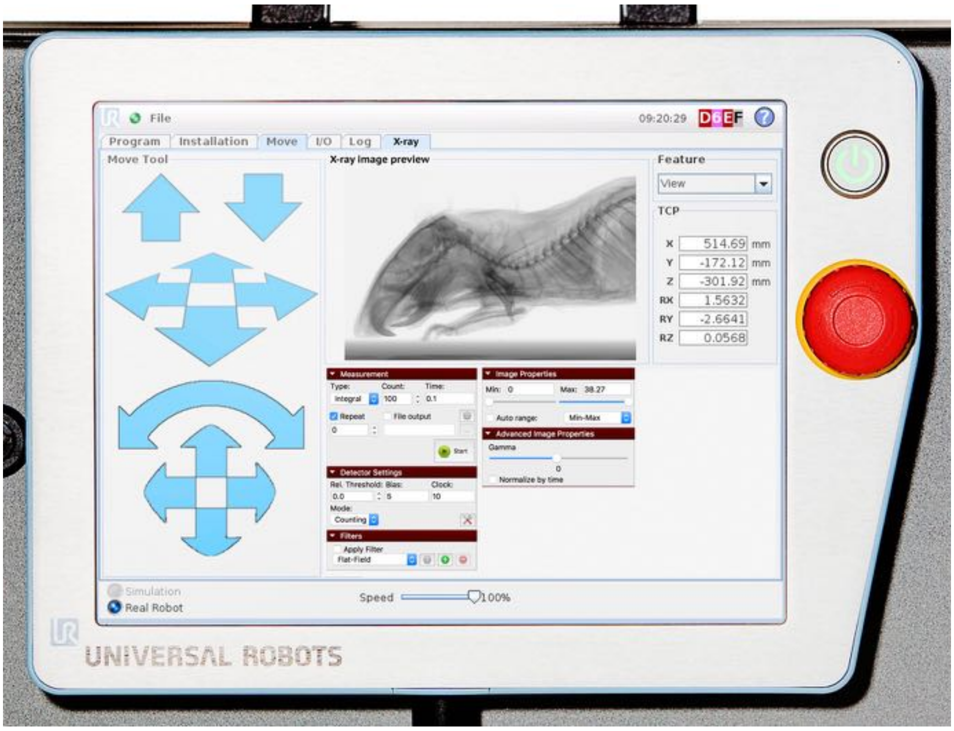

Fig.7 A possible implementation of the detector & X-ray tube control into the PolyScope software operated by the portable touch screen of the Universal Robots controller. The robot movement control buttons remain accessible for online change of the X-ray view direction.

The easy manual programming is the major advantage of UR collaborative robots. The easiness of use even in case of otherwise highly complex (3D) X-ray imaging is a paramount of our efforts.
However, the flexibility of the system and possibility of reprogramming brings also risk of human errors. The automatic robot collision sensing of collaborative robots is therefore an important advantage compared to regular industrial robots since it prevents possible damage of inspected objects. The workflow for the operator would be as follows:

1. X-rays are off, X-ray cabinet/room open. Operator manually moves the robot to the position for inspection. This could be repeated several times to record all positions where images should be taken or define start/end points of scans.
2. Closing X-ray shielding.
3. Turning X-rays on from PolyScope and starting acquiring images. An online preview of images will appear on the screen of the master computer and also on the robot control unit in the appropriate tab for X-ray control.
4. The system stores the images locally or sends them for further processing and analysis.
5. X-rays are automatically turned off when the scan is over and the system is ready for next sample.

The master computer has enough computing power to do also processing of the 3D data. It is possible to integrate this system into production line and connecting the resulting outputs to factory QA systems. Radalytica is also developing customized automated analysis of acquired 2D/3D data to provide “yes/no” info to a production line to determine whether the inspected product passed the X-ray check.

The model case: system for aileron inspection

Fully composite parts of aircrafts are exposed to high loads even in light airplanes such as the high-performance glider shown in Fig.8. Thus, reliable and repeatable methods of defect identification are of a high importance. Therefore, an aircraft part was selected as a model case for the robotic X-ray inspection system use.

Fig.8 Fully composite parts of aircrafts are exposed to high loads even in light airplanes such as this high-performance glider.

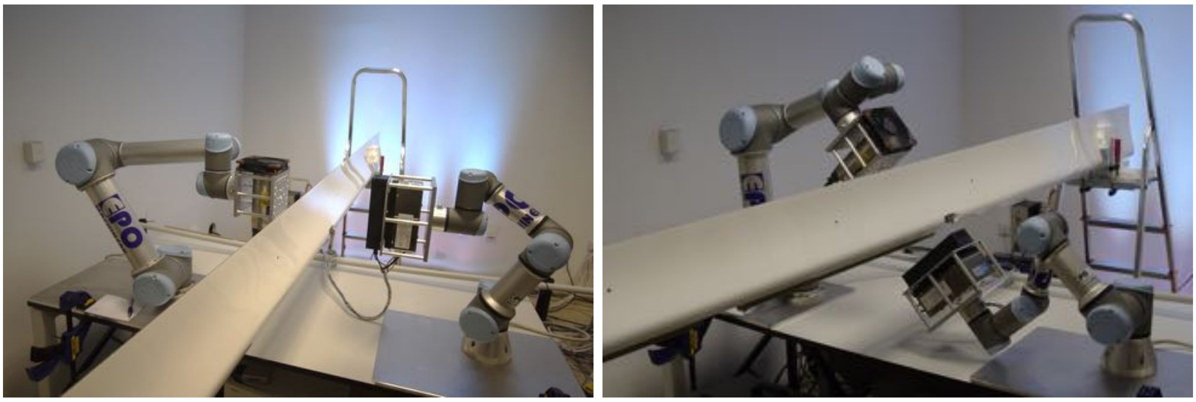

Fig.9 Flexibility of the robotic system is demonstrated on inspection of a glider aileron: besides 2D scanning (left image) it is possible to inspect critical parts of the aileron, such as joints, under arbitrary angles (right) revealing locations of defects otherwise hidden in the 2D scan.

The system was tested on an inspection of an aileron. It is an ideal sample for robot use as it is:

- a large sample that
- requires full 2D scan and
- requires high-detail inspection of selected areas under variety of angles.

Moreover, the sample is made of mostly light materials that are ideal for the X-ray imaging technology used. Critical places of the sample are in this case close to joints that are glued into the composite material of the aileron. However, the steel of joints prevents reliable detection of defects in the composite material as it creates too dark shadow in X-rays. The only solution is an inspection from a variety of angles.
The scanner prototype is shown in Fig.9. A full 2D X-ray scan of a selected area was performed. The result of the whole scan is shown in Fig.10. Details of inserted steel parts viewed from different angles are in Fig.11 and Fig.12. A video from the scan including angular views could be seen at https://youtu.be/9TmV0ca-4eg.

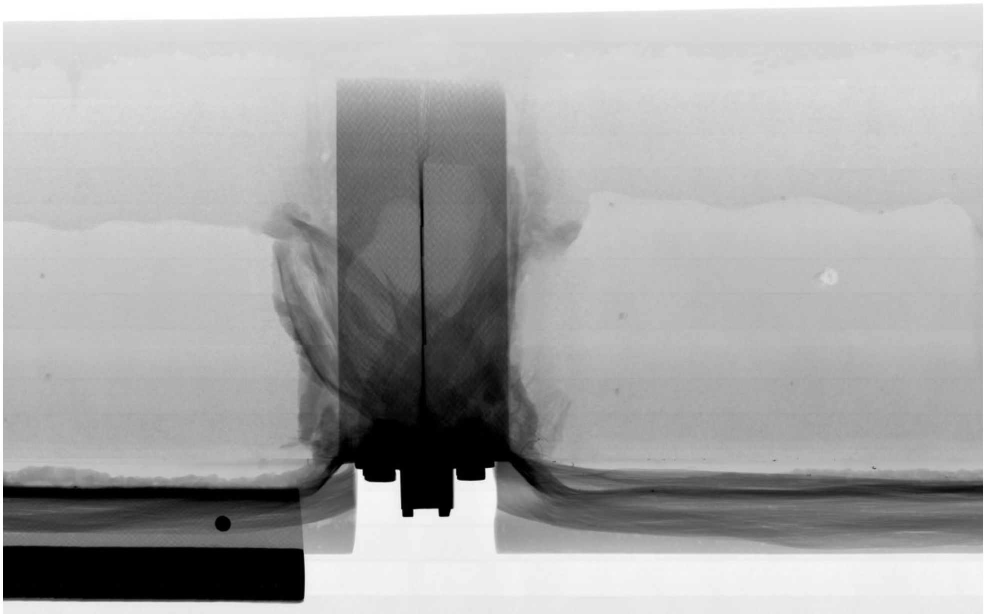

Fig.10 Final X-ray scan of the selected area of the glider aileron. The darkest areas are metallic parts inserted into the composite aileron. Inspection of quality of their fixation into the composite is therefore difficult without angular views.

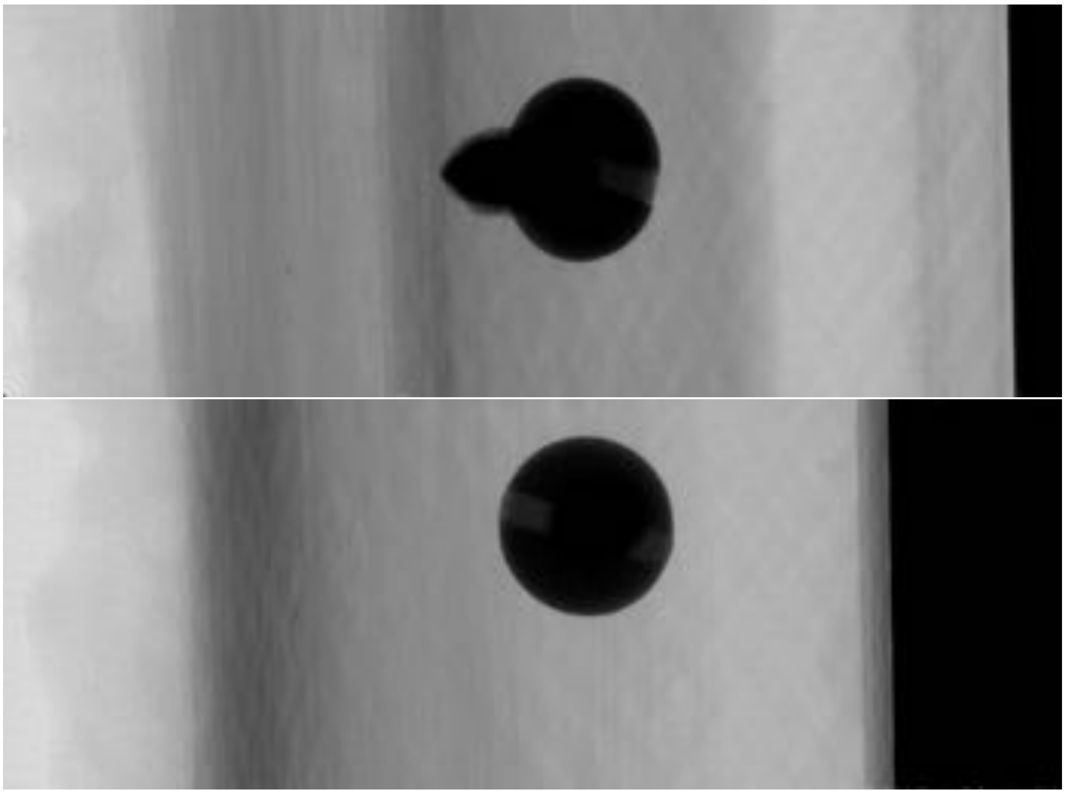

Fig.11 Screw inserted into the composite easily viewed from two angles.

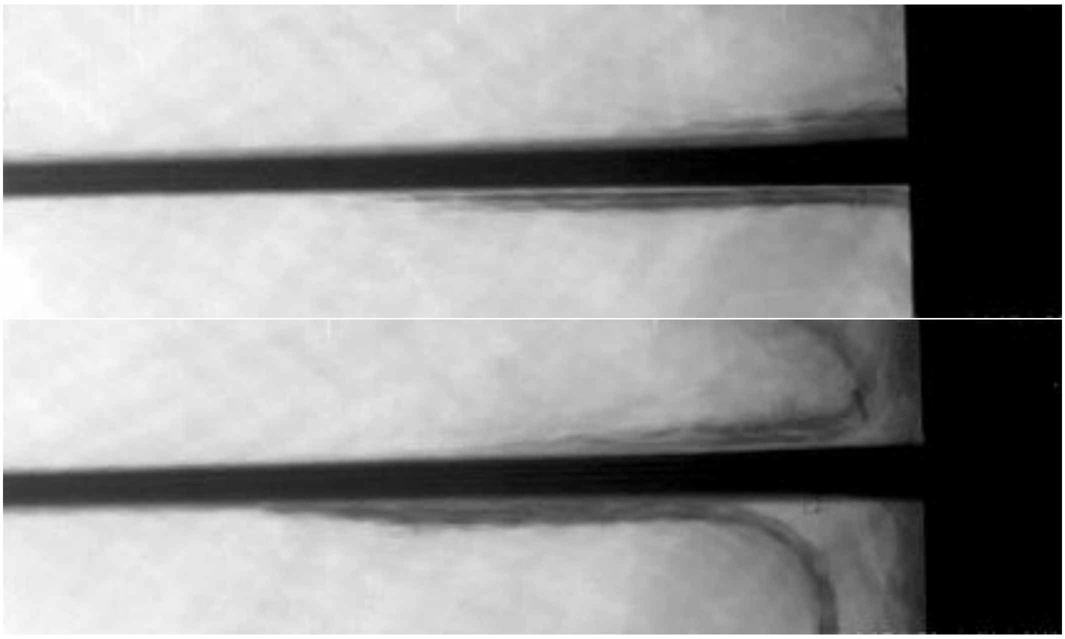

Fig.12 A steel pin inserted into the composite viewed from two angles. It clearly reveals differences of pin fixation into the aileron in each direction.