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Image guided ion beam irradiation unit IRRADION

Technology description

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X-rays reveal internal structures of inspected samples. Both the X-ray tube and the detector in classical X-ray imaging systems are 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.

Fig. 1 Photography of the existing robotic scanner RadalyX for general inspection applications. The devices allows large area 2D scans, computed-tomography and real-time X-ray inspection.

Contrary to the classical X-ray system, the robotic one allows nearly arbitrary flexibility of view angles.

The major advantages of the X-ray scanner based on pair of robotic arms are:

- integration of direct conversion photon counting X-ray detectors,

- high resolution (55 μm or better[1]) imaging of large objects,
- real-time imaging with immediate viewing angle and position control,
- variety of scanning modes for different sample types,
- arbitrary plane of scanning or scanning over a complex shape,
- spectral X-ray imaging for material identification.

The key parts of the scanner are two robotic arms with 6 joints. The first arm holds an X-ray tube, the second holds an imaging detector. The X-ray tube/detector pair can, thanks to the robots, move and rotate freely about the sample. The robots are moving synchronously so that the mutual position of the X-ray tube and detector remains the same under all circumstances.

Real time X-ray inspection

The automatic scanning modes are used to create an overall image of the inspected sample. The system can be switched to a real-time imaging mode where the robot position and orientation is controlled via a 3D mouse (Fig. 2).

The 3D mouse allows the full control of position, pitch yaw and roll of the X-ray image view. The X-ray image of the given sample area is shown in real-time on the screen. The smooth manual control of the view with the online image stream creates a perfect tool to localize defects in the inspected structure in 3D.

The real-time imaging is shown on videos under this link:

Radalytica youtube channel[2]

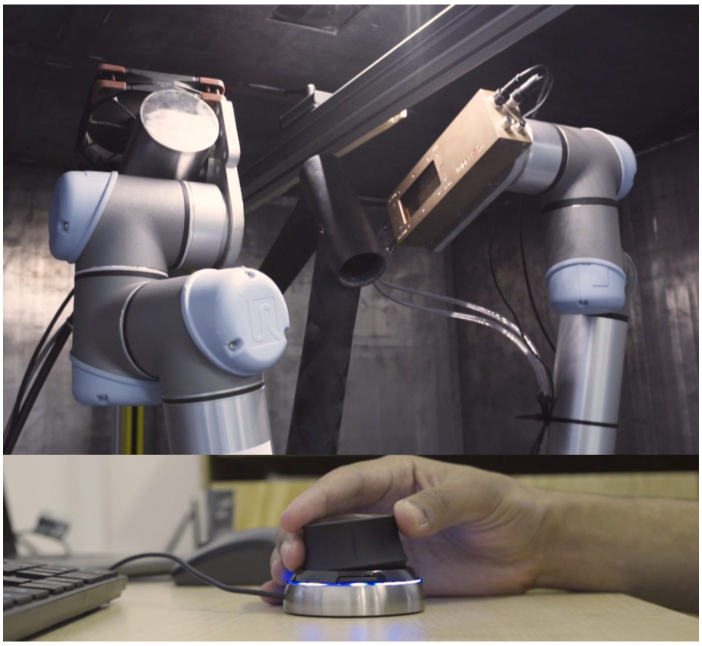

Fig. 2 X-ray view can be controlled online using a 3D mouse. Position, pitch, yaw and roll of the view can be smoothly changed while observing real-time X-ray images.

The immediate feedback between the manual view direction control and the X-ray image is what makes the system very intuitive to use. Thanks to the link between the image and our action the brain is able to create a very clear idea about the 3D structure of the sample without the need of usually slow, complicated and high-dose measurements like computed-tomography (CT) that requires similar approach in the analysis of acquired 3D volume anyway. Therefore, inspection with robots is compared to CT faster, less demanding on the data processing and can be applied to a selected area of a larger object.

[1] Achieved using geometrical magnification.
[2] https://www.youtube.com/channel/UCY_z2ikSWTB0h3JJCoBZFrQ/videos

Irradion

The Irradion project modifies and extends the robotic scanner for purposes of research on cancer treatment with ion beams on small animals (mice or rats).

The Irradion system is co-funded from Eurostar-Eureka programme. The project partners are Radalytica a.s. which is SME focusing on robotic imaging systems integration. Next partner is Smart Scientific Solutions B.V. also SME developing irradiation planning software for biological and preclinical research. The third partner is Maastricht University which is responsible primarily for experimental evaluations of the system.

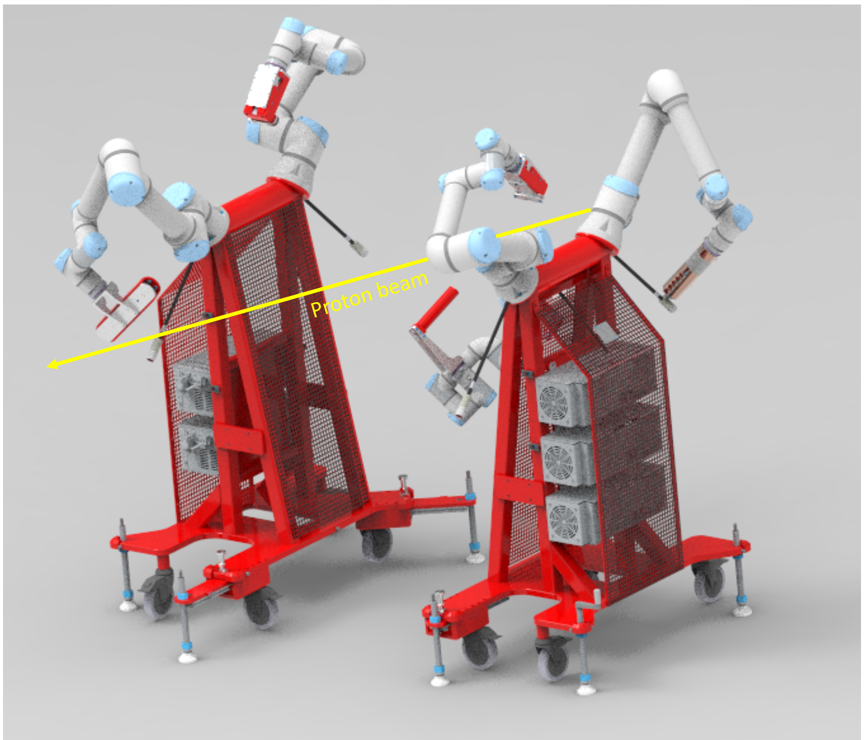

Fig. 3 Irradion unit. It integrates 5 robotic arms. Two for X-ray imaging, two are for ion beam monitoring and proton CT and the fifth arm carries the animal.

The Irradion unit integrates five robotic arms for X-ray imaging, ion beam tracking and for positioning of the animal in respect to the beam. The system is portable, easy to be installed and removed, since the plan is to offer it as a research platform for therapeutic ion beams.

Imaging

The imaging subsystem of the Irradion is nearly identical to the industrial robotic scanner RadalyX. It integrates X-ray single photon counting imaging detector with 1 mm thick CdTe sensor. The detectors offer a very high detection efficiency combined with high resolution of 55 µm. This makes them ideal for small animal imaging as high-resolution images can be measured without excessively increasing the radiation dose. In addition, the fast frame rate[3] of the detector allows dynamical imaging of the animal and adaptive adjustments of the irradiation based on animal movement in the future[4].

In addition, the photon counting detectors allow X-ray photon energy discrimination which can be used to suppress scattered radiation, thus improving the image contrast. It can also serve to measure absorption spectra and recognize different types of materials (tissue). This is especially important for improvement of the irradiation planning where there is not always a simple connection between Hounsfield units of a common CT scan and irradiation properties of tissue. A spectral X-ray image of a PlastiMouse is shown in Fig. 4.

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[3] The current range of supported detectors offer 20 to 40 frames per second. The new generation will offer 200 to 400 frames per second. This generation will be available in Q4 2020.
[4] This option is subjected to ongoing research.

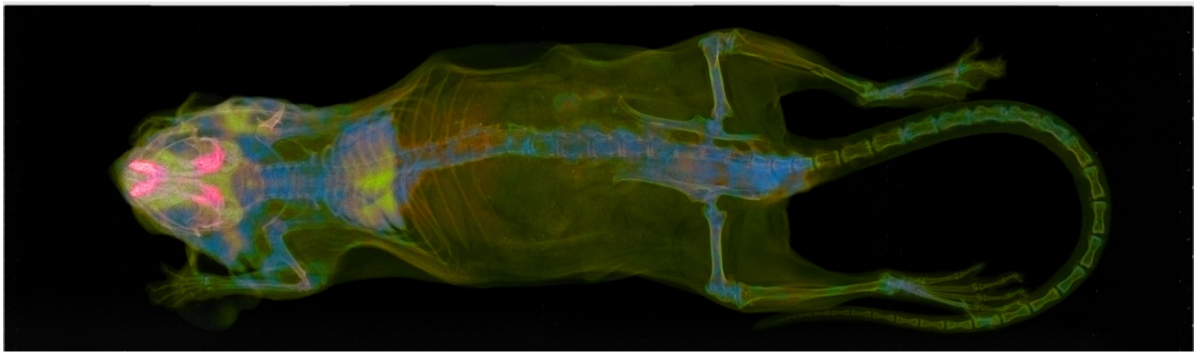

Fig. 4 Spectral X-ray image of a PlastiMouse phantom (SmART Scientific Solutions BV). The colours are assigned to pixels based on similarities in the absorption X-ray spectra between different types of materials (tissue) found in the object. The sample was measured using the RadalyX robotic scanner.

The flexibility of 6-axis robotic arms used in the scanner allows image acquisition by means of cone-beam Computed Tomography. An example of a reconstructed volume is in Fig. 5. Selected slices of the volume are in Fig. 6.

Fig. 5 3D visualisation of the plastimouse CT reconstruction. The data were measured using the RadalyX robotic scanner.

The spatial resolution of the CT reconstruction is currently about 100 μm. However, part of the project is improvement of the geometrical calibration that would improve the resolution to the native detector resolution of 55 μm.

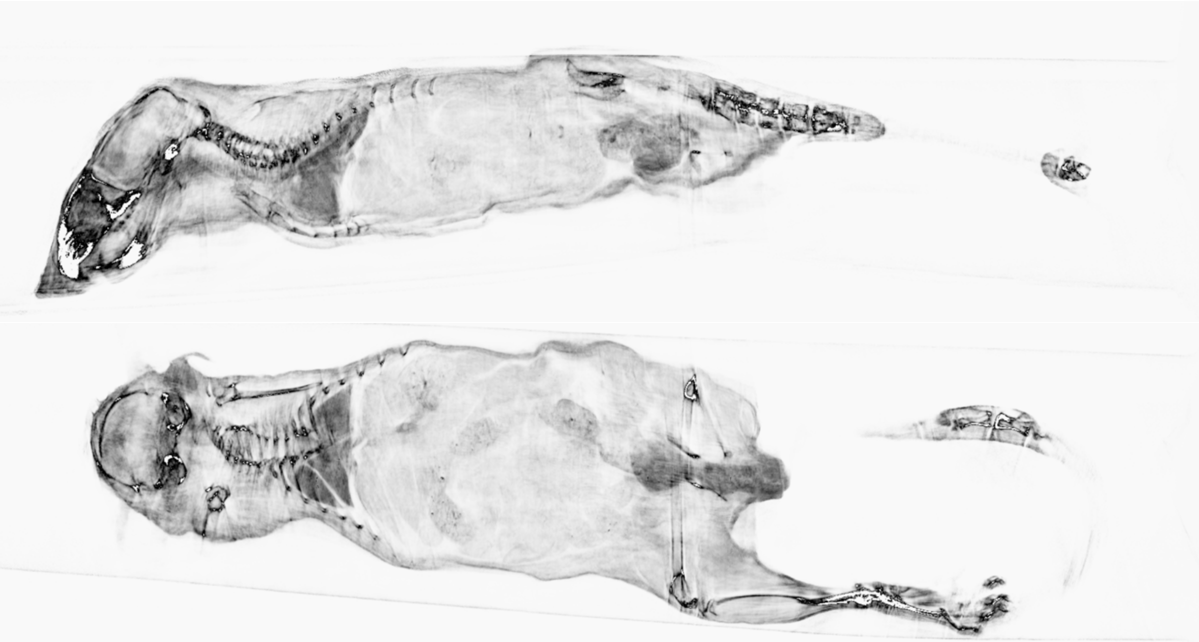

Fig. 6 Slices of the PlastiMouse CT volume.

The options of X-ray video recording and the real-time imaging will remain also in this imaging platform.

Animal positioning

The animal positioning is implemented using smaller robotic arm. The animal is placed into heated bed with possibility to connect anesthetic gas. Advantage of this solution is in the possibility to freely position the animal with respect to the imaging robotic arms and/or with respect to the beam(s). One requirement is to allow exactly the same irradiation geometry with ion beams and photon beams. Positioning of the animal using the robotic arm allows integration of other irradiation beams (photons) at different locations near the system.

Particle tracking and calorimeter

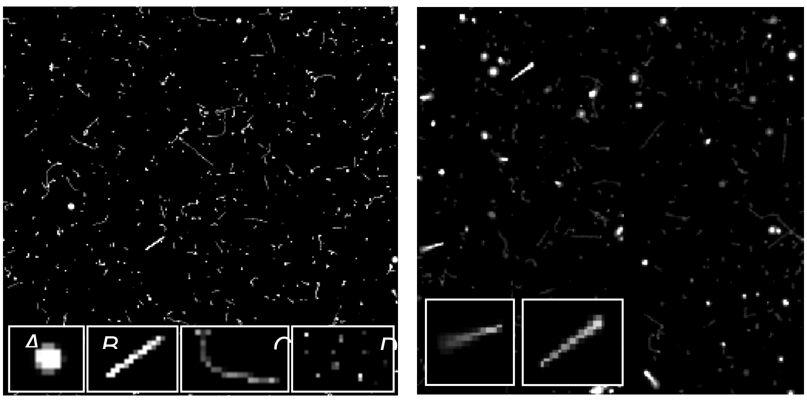

Fig. 7 Examples of tracks of various particles measured by the detector. On the left: alpha particles, MIPS, electrons, X-rays. On the right: proton tracks.

The device will be equipped with a pair of particle tracking detectors based on Timepix3 pixel chips attached to two robotic arms. Timepix3 is the world’s first imaging detector operated in the list mode. The device does not measure only a sequence of images, but it produces a stream of data. Each word in the stream corresponds to a single particle hit and contains information on position, energy and time when the event occurred. The pixelated chips allow visualization of particles tracks through the device in 3D (using timing information from the charge collection across the sensor). One of these detectors will be located before the animal and the second behind. Tracks of protons or ions through the animal will be measured and this information will serve to reconstruct proton (ion) CT data and to improve irriadiation planning.

The second robotic arm carrying the rear detector will carry also calorimeter to stop the particles and measure their residual energy. The calorimeter is based on very radiation hard YAG:Ce crystal with electronics operated in list mode and fully synchronized with the tracking detectors.

Irradiation planning software

To ensure effective use of the Irradion system, an image-based treatment planning system is included. It enables beam planning and Monte Carlo dose calculation for photon and proton beams. It is based on the existing commercial products SmART-ATP and SmART-XPS (SmART Scientific Solutions BV), and provides an intuitive user interface for reading CT images of small animals, beam planning, dose calculation and dose analysis. Fig 8 provides a snapshot of one of the functions of the treatment planning system. In the Irradion project, the system is extended for proton dose calculation and the use of proton CT images for stopping power extraction.

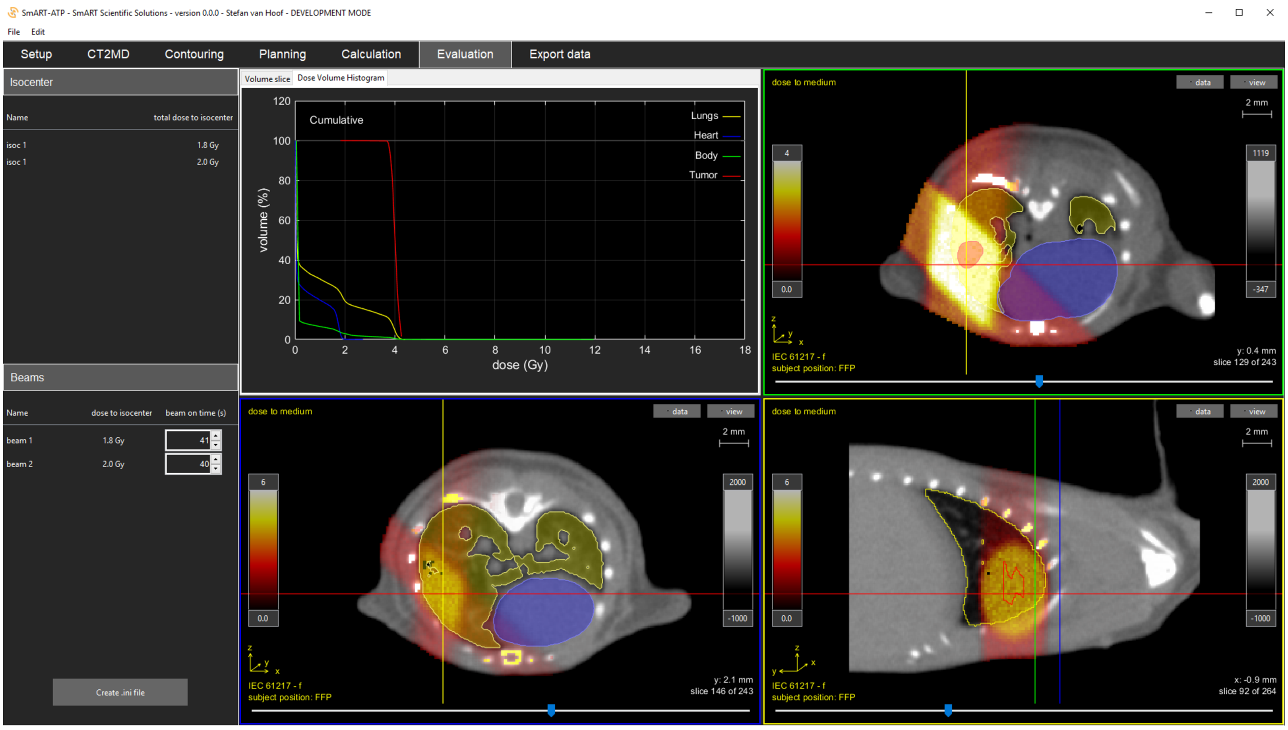

Fig. 8 A snapshot of the user interface of SmART-ATP for visualization of the radiation dose from photon beams in a mouse specimen.

Other applications of the robotic scanner for research

The X-ray imaging systems that could be installed at the accelerator facility can find use in other fields outside of biological and preclinical research.

Installation of this imaging system can establish an imaging facility useful for a number of other research teams from different fields, including from outside the institute.

X-ray imaging

The X-ray imaging subsystem is virtually the same as the one used in RadalyX system for variety of X-ray imaging tasks. It is, thanks to the novel very sensitive X-ray imaging detectors, well suitable for analysis of new material properties. Radalytica is using the system for X-ray imaging of carbon fibre reinforced plastic composites that are used in aerospace, but also in automotive industry. The spectral X-ray imaging finds its use in analysis of cultural heritage. The power of X-ray absorption spectrometry is in Fig. 9. It shows a photo and an X-ray image of a painting. The X-ray image reveals only a single material (pigment) that was used in the otherwise overpainted nude.

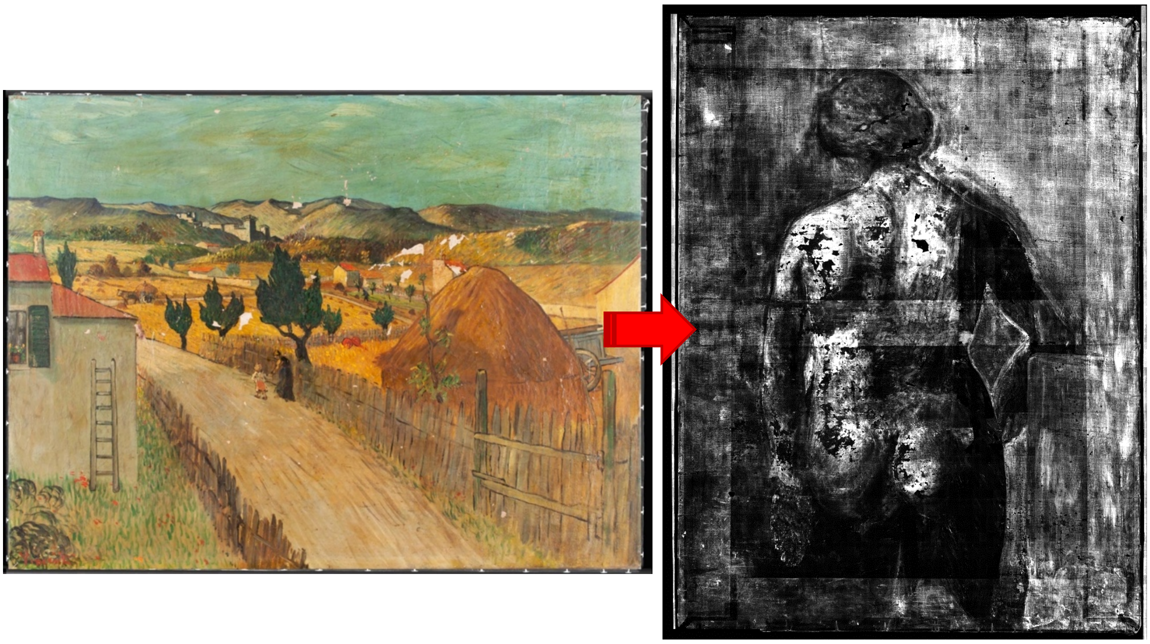

Fig. 9 Photo of a painting (left) and X-ray image (right) revealing the overpainted nude. The hidden image was extracted based on material analysis obtained from the X-ray transmission spectra.

The 3D CT imaging can be used for a variety of technical samples. The real-time X-ray imaging can be applied for studies of dynamic processes including in in vivo specimens.

Modularity

X-ray imaging is not the only imaging modality available. The device is by default equipped with laser distance measurement. This can be used to create 3D maps of object surfaces for example for metrological purposes. Radalytica is also developing a range of other imaging modalities. These imaging probes are easily interchangeable on the robotic arms. The same robotic platform can therefore perform a variety of imaging tasks and can be also extended in the future as new imaging modalities become available or as new research requirements or as TimePix technology evolves will arise.

Air-coupled ultrasound

Radalytica in collaboration with company SONOTEC GmbH integrates air-coupled ultrasound probes. These are in particular powerful for detection of delaminations in composite materials which are virtually invisible by X-rays. The air-couple ultrasound finds also other uses in material, aerospace and other research fields.

X-ray diffraction

The new types of energy sensitive imaging detectors have a significant impact also to X-ray diffraction. Measuring the spectrum of diffracted photons means that any monochromators on the X-ray source side can be eliminated. This significantly reduces complexity of the XRD system and allows its integration with robotic arms. Radalytica is now starting another Eurostar project to develop such modules. Large area XRD scan will be possible and the analysis of crystalline structures will be possible in vivo. The XRD system can be easily combined with XRF for precise elemental analysis.

Macrophotography, hyperspectral imaging, UV, infrared

Other imaging modalities that are under development or on the R&D roadmap are high resolution photography of object surfaces, hyperspectral imaging, UV and infrared imaging. Many of these methods are in particular interesting for analysis of cultural heritage.

Summary of the system

We are offering the following image guidance system:

- X-ray imaging & CT subsystem, that includes:
  - pair of 6-axes robotic arms,
  - photon-counting X-ray detector with CdTe sensor of 28x70 mm in size,
  - X-ray tube (50kVp, 1mA, emission spot 30 μm),
  - CT acquisition and reconstruction,
  - real-time imaging
- Particle detection system:
  - pair of 6-axis robotic arms,
  - two Timepix3 based detectors with CdTe sensor and list-mode readout.
  - Yag:Ce crystal based calorimeter.
- Animal positioning:
  - 6-axes robotic arm,
  - heated mouse bed.
- Mechanical support.
- Control and image data processing software.
- Custom developed irradiation planning software.
- Installation, commissioning and 5 day training at customer's site.

Lead time:

- 6 months for hardware,
- 12 months for the final version of the irradiation planning software[5].

A formal quotation would be prepared based on mutual agreement of delivered items.

[5] The software is under development under the Irradion project. Beta versions will be available together with the hardware delivery.

About us

Radalytica a.s. is developing and producing X-ray imaging systems that combine cutting edge X-ray imaging detectors with the flexibility of collaborative robots. We are building systems that give customers the best X-ray imaging quality for non-destructive testing of light advanced materials.

The company was established in 2016. Yet, the team has over 20 years of experience in photon counting detectors and X-ray imaging and development of industrial applications.

Radalytica is currently the only commercial company offering fully integrated X-ray imaging systems based on dual robotic arms. Especially with photon counting detectors that have only recently entered the market. It is therefore opening entirely new horizons not only in the X-ray imaging field, but generally in the non-destructive testing industry.

SmART Scientific Solutions BV is an R&D company that was established in 2015 and is located in Maastricht, the Netherlands at the Brightland Maastricht Health campus, where many startups are housed. It is a spinout of Maastro Clinic, a well-known radiotherapy research clinic, which is part of the GROW School of the University of Maastricht. Despite being a young company, SmART Scientific Solutions is close to obtaining a majority position in selling software to OEM hardware manufacturers for dose calculation in image-guided precision irradiation, which is a novel research field. This research field is very high-tech and rapidly growing, and aims to develop methodologies to assist translation of preclinical research into clinical practice, in particular in the field of radiotherapy for oncology. SmART Scientific Solutions has worked mostly with OEM PXi so far, but also signed a contract in 2019 with the only other OEM in this field, XStrahl. Sales through this contract will increase rapidly in 2021.

SmART Scientific Solutions has strong links to the human radiotherapy world, and Dr Verhaegen is co-founder of SmART Scientific Solutions and Head of clinical physics research at Maastro Clinic and professor at the University of Maastricht, ensuring a strong link between these organizations and bringing many years of experience in project management. SmART Scientific Solutions' key product currently is SmART-ATP, a basic treatment planning system for photon precision irradiators for small animals. SmART Scientific Solutions is rapidly growing and employs currently three salaried employees, besides the co-founders.

Besides treatment planning software SmART Scientific Solutions is developing phantoms for animal imaging, dose viewing software for traditional biological irradiation cabinets and has designed a data warehouse system for preclinical research.