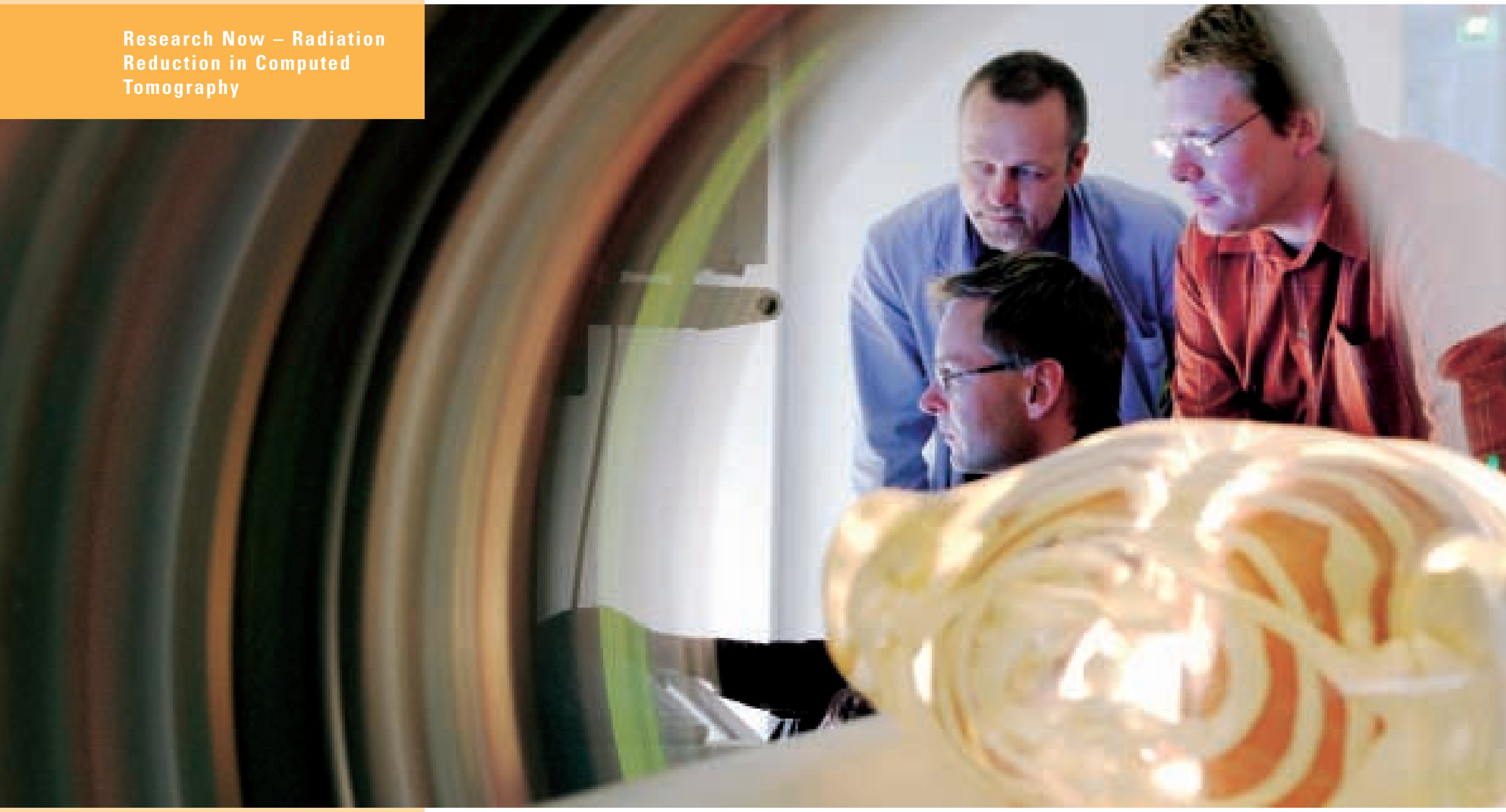
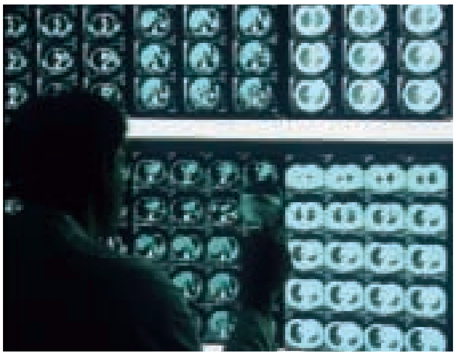


Better Computing of Images –
Reducing Radiation in Computed Tomography

A broken leg, a painful tooth root, suspected breast cancer or pneumonia – the doctor takes X-ray pictures. The high-energy radiation has become indispensable in everyday medical practice. Nearly 40 per cent of medical radiation exposure comes from computed tomography scans and the number of CT scans will continue to rise in the future – and radiation exposure with it. Scientists at the GSF Institute of Radiation Protection have developed a new process which provides high-quality scans with a clearly reduced radiation dose.

In 2001 each German citizen is estimated to have received a mean effective X-ray dose of about two millisievert (mSv) in medical examinations on average. This means that with a mean total exposure of 4.7 mSv X-rays make up the lion's share of radiation exposure. According to the Federal Agency for Radiation Protection nearly 40 per cent of the two mSv comes from computed tomography (CT) scans, which, however, are only about five per cent of all X-ray scans. In computed tomography images of slices of the

In computed tomography images of slices of the body are shot. Reassembled they give the physician an accurate picture of the interior of the body. Multislice CT, which was introduced a few years ago, allows the simultaneous calculation of several adjacent layers of the body.



body are shot. Reassembled they give the doctor an accurate representation of the interior of the body. CT is advancing continuously, particularly since new processes make it more and more powerful: more shots in less time, more diagnostic possibilities. Thus, Multislice CT, which was introduced a few years ago, allows the physician to look at several adjacent layers of the body at the same time. This means that the number of CT scans will continue to rise in the future.

It is a disadvantage that CT implies comparatively high radiation exposure: as opposed to classical X-rays regions of the body which are not of interest are more difficult to shield, all parts of the body in the direction of the scan are irradiated; on top of that the radiation dose at the point of entry into the body is slightly higher. Scans of one to two CT layers carry a similar radiation exposure to that of a conventional full-size X-ray of the same region of the body.

Technical improvements have so far been able to reduce the dose per CT by a maximum of 30 per cent. With a further reduction of the radiation dose, however, the image quality would suffer, mainly due to greater image noise. The goal of the GSF Working Group Medical Physics is to find a way to generate high-quality scans despite a lower dose. The head of the Working Group, Dr. Christoph Hoeschen, outlines its work: "For the necessary reconstruction of the images from CT data we apply a novel algorithm, which makes better use of the information contained in the raw data." This means that the scientists can reconstruct images of at least the same quality as with the standard procedure used in the past, "filtered back projection" (FBP) with a comparable extent of computing with half the data, i.e. half the radiation exposure. On the basis of the new algorithm they have also developed various new scanning geometries which could help to reduce the dose even further without losing any of the quality.

Modern Multislice CT technologies offer more diagnostic possibilities. This also means that the number of CT scans will continue to rise in the future.

Existing Standard

The algorithm of FBP consists of two main steps: back projection and filtering. "The data are recorded as projection radiographies from different angles. For simplification we assume that the rays belonging to one angle run parallel," Hoeschen explains. "Then the total data record forms a so-called sinogram. After that we project the result back: we assign an absorption value to all elements on the respective projection line, so that the total absorption value measured would result. If we do this for all projection radiographies, we get an approximation to the original image." The more angles are used to "shoot" the rays, i.e. the more projection radiographies are produced, the better will the image be. But a point object will appear as the shape of a star. Filtering turns it back into a point, but also blurs the image to a certain extent. To minimize this effect, very high-definition measuring is required using photon-rich rays, so that the image noise does not get to great. I.e.: high radiation exposure must be accepted.

Together with colleagues from the University of Oregon in Eugene, USA, the GSF scientists have created a novel reconstruction algorithm, which can calculate image data from the raw data of a CT scan.

New: Algorithm OPED

Its principle, an "orthogonal polynomial expansion on the disc" (OPED), is not easy to

For the reconstruction of images from CT data the scientists from the GSF Institute of Radiation Protection apply a novel algorithm which makes better use of the information provided by the raw data. This means that they can reconstruct images of at least the same quality as with present standard methods with comparable computing from half of the data – i.e. half the radiation exposure.

understand for non-physicists. The principle is based on the fact that a function describing the object can be represented approximately by a polynomial. By carefully selecting the required basic functions the experts manage to reconstruct an extremely accurate approximation of the actual properties of the object fairly easily with relatively little computing. Correct data input is a prerequisite – for the CT this means: enough photons must penetrate the absorbing medium to generate detectable signals.

Reconstruction using FBP implies yet another problem apart from that of a blurred image, which is caused by the indispensable filtering: the rays which do not run in parallel, but like a fan. But since most conventional FBP versions necessitate parallel rays, they must be calculated from the fan beam, which may result in mistakes in the reconstruction. With the OPED algorithm raw data from rays at different distances can be used: the required data can be obtained right from the scans shot with fan beam. The data just have to be resorted, then the reconstruction can be started immediately.

Better Images With Half the Radiation Dose

The GSF scientists prove in test simulations that OPED need not fear the comparison with FBP: using technical objects and layers of the voxel models of human bodies made by them they simulate original data as an actual CT would produce them. These data are then reconstructed using FBP once and OPED once from half of the FBP data. These images already give the impression that OPED does very well – the OPED image reproduces details more clearly without considerably greater noise. Quantitative evaluations of technical phantoms show: with OPED at least the same signal-to-noise ratio is possible with half the dose as it is with FBP with the full dose. So using the new algorithm the dose can be halved without sacrificing quality.

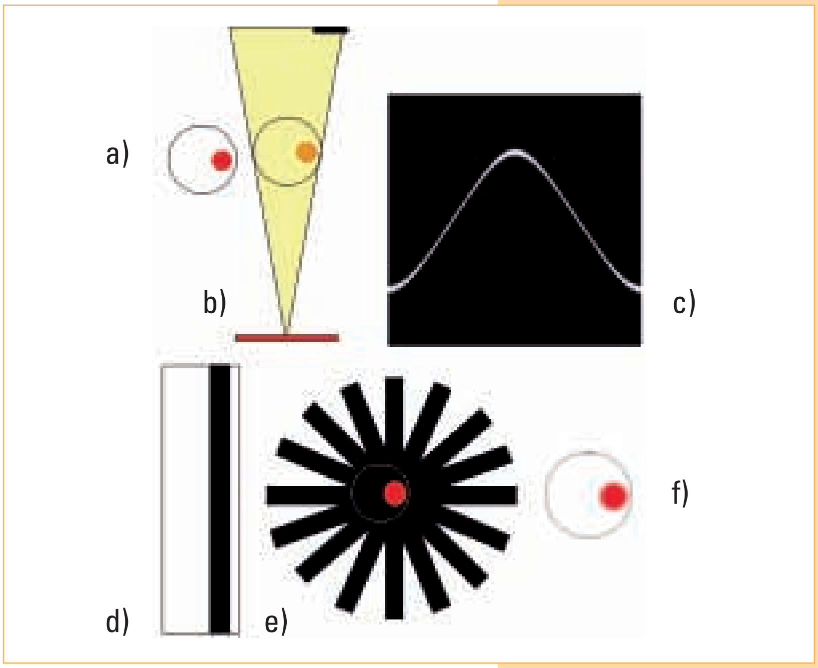
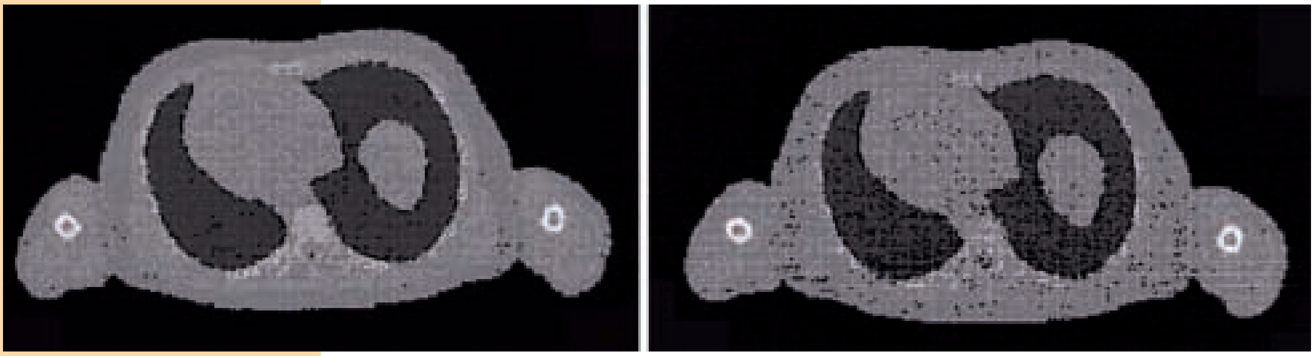


Image production in the computed tomogram with filtered back projection: a) object, b) projection, c) sinogram (image from all projections), d) one back projection, e) sum of many back projections and f) filtered resulting image.

Advantageous Geometries

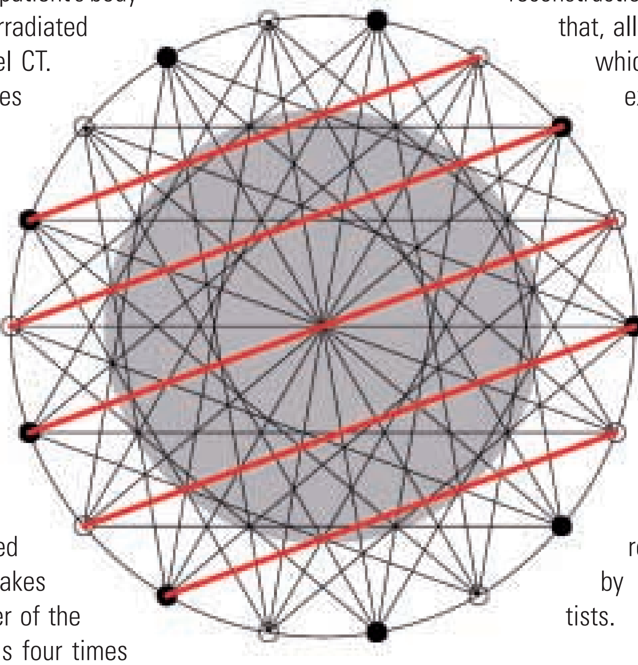
One aim of medical imaging is to record more and more layers of the body at the same time in order to minimize artifacts caused by movements, e.g. in heart scans. For this purpose it would be desirable to combine CT with modern digital X-ray image detectors, so-called flat-panel detectors. This, however, involves two serious problems. One is associated with the fact that the detector elements are no longer arranged on a circle, but in a flat surface; this means that they should be of different sizes – getting bigger towards the edges. Since when in the conventional process the fan beam impinges on detector elements of equal size and in a circular arrangement, after it has penetrated the patient, all part beams arriving there are of the same width. With the flat-panel detector, however, the part beams are of different widths. “This causes many problems,” says Hoeschen. “But we can solve them, because OPED does not have to rely on beams of equal width – in particular, because the beams need not be arranged at equal distances. So we vary their distances and thereby their widths. If this is done skillfully, it can be arranged in such a way that beams of equal width impinge on the detector after passage



The voxel model GODWIN developed at the GSF is based on standard values and represents an average person. The International Radiation Protection Commission chose Godwin to be the future reference human for dose assessment. Picture: A reconstructed layer from the voxel model GODWIN: a) Reconstruction by standard method (filtered back projection FBP): b) Reconstruction by new algorithm (OPED) from half of the FBP data.

through the patient after all – so that there is an optimal utilization of the detector."

The second difficulty is that a large portion of the patient's body surface is irradiated with flat-panel CT. This generates much scattered radiation, which superimposes the actual measured signal. While with conventional CT the scattered radiation makes up one quarter of the direct ray, it is four times its size with flat-panel CT. "So we have a sort of scattered ray image. But we will get a grip on this, we will use masks to blank the rays which are not required. This can drastically reduce the portion of scattered radiation," says Hoeschen.



Positions of an X-ray source (= black dots), from which fan-shaped rays emerge. The white dots are detectors. Resorting of the rays (red lines) results in parallel, but not equidistant, dots.

There is yet another disadvantage of current CT systems which could be compensated for by OPED – by coupling the algorithm with a completely new geometry. To minimize scanning times, the CT tubes do not only emit radiation while the detectors are reading out, but generally continuously. Since fewer rays are sufficient for OPED and, in particular, rays at variable distances, a fixed inner ring could be installed in an existing CT system, which has two functions: it is both a mask and a detector for a second scanning level. This would provide two data records for reconstruction. Apart from that, all the radiation to which the patient is exposed would be used for imaging, which would allow a further considerable dose reduction without a reduction in quality. A prototype of this kind is currently being built by the GSF scientists.

The new OPED process has yet to go on to commercial application. But tests have started, and there are ample indications that OPED will pass the evaluation phase successfully. So hopes that a milder computed tomography can enter medical practices and clinics in the foreseeable future seem to be justified.

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