letters

continued from page 15

goal to construct by "the year 2000 the first manned structures in space for the conversion of solar energy and other extraterrestrial resources" for the "use of human beings everywhere." The second resolution, House Concurrent Resolution 447, supports Teague's resolution, and was submitted by Corinne C. (Lindy) Boggs (D-Louisiana), David A. Stockman (R-Michigan) and Barbara A. Mikulski (D-Maryland). Both resolutions are expected to be voted on during the current session of Congress. We urge all our colleagues to write their representatives in support of these resolutions. (House of Representatives, Washington, D.C. 20515.)

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Higher-resolution tomography

The article by William Swindell and Harrison Barrett (December, page 32) on computerized tomography "suggests that future improvements in resolution or signal-to-noise ratio will be achieved only by increasing the patient dose. Because this is normally unacceptable, significant improvements in resolution should not be expected." I beg to differ with this remark, especially since it tends to discourage research on the important problem of dose reduction in computed tomography, an area in which your readers might profitably work.

I have reviewed some of the many possibilities for substantial dose reduction in computed tomography,[1] and the National Cancer Institute of the National Institutes of Health is issuing contracts for "Reconstruction algorithms for dose reduction in x-ray computed tomography."[2] This is an area which has, for the most part, been ignored by the commercial manufacturers of x-ray scanners, primarily because most of them have focused on only a single, computationally rapid algorithm (convolution) and because high dose permits sharp images, which improve sales.

The argument that the resolution limit has been reached is based on at least two assumptions: that the reconstructed image is a linear function of the data and that no *a priori* information is available about the object being reconstructed. Such assumptions lead to a worst-case estimate of the signal-to-noise ratio. Nonlinear algorithms and intelligent use of known information should improve the signal-to-noise ratio considerably, although both are generally lacking from the software of commercial scanners.

But beyond these considerations, it is clear that the time has come for physicists to take a fresh look at the problem of reconstruction from projections. The very formulation of the equations used for reconstruction is subject to doubt. Consider the detector width, which is 3 mm or more in most commercial scanners. It is this width that gives rise to the "line" integrals (really strip integrals) which are the starting point for all common reconstruction algorithms. It is not necessary to collect the data this way. With available technology one could measure many of the dynamic properties of each photon or particle transmitted or scattered through a patient. In particular, spatial resolutions of 0.1 mm or less should be attainable in determining where an x-ray photon strikes a detector. Thus we see that much of the information is thrown away by the very method of data collection. This mode of data collection is dictated by mathematical presumptions rather than the fundamental physics of the problem.

The spatial resolution of x-ray scanners is seven orders of magnitude worse than the Rayleigh limit for x-rays. By careful study of the physics of the interaction of radiation with tissues and with detectors, and by the development of new classes of inverse scattering algorithms for reconstructing images from recoverable data,[3] I expect that it should be possible to get much closer to the latter limit without increasing the dose to the patient.

The rewards for such efforts are great: Higher spatial resolution could catch many tumors during their long, slow growth phase (up to 1–3 mm diameter), a stage during which, moreover, they are not likely to have metastasized (sending cancerous cells throughout the body); screening of asymptomatic people might become acceptable, rather than waiting for the late stages of massive disease. Today there are few circumstances in which we can detect such small tumors. Computed tomography at sufficiently low dose might make it possible to screen each person as part of a regular checkup for cancer and an enormous variety of other pathological conditions.

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THE AUTHORS COMMENT: We share Richard Gordon's conviction that nonlinear algorithms, especially those that incorporate *a priori* information about the object, will prove valuable in computed tomography. Indeed, we are among the bidders for the NIH contracts to which he refers. We also agree with Gordon concerning the need for higher spatial resolution in computed-tomography images. Much of our current research,[1] which uses film as a high-resolution detector, is directed to this end.

We cannot, however, endorse the optimism shown by Gordon in the penultimate paragraph of his letter. For example, his statement that it should be possible to get much closer to the Rayleigh limit without increasing patient dose ignores some rather basic statistical limitations. As we have shown,[2] the required patient dose with any linear algorithm varies inversely as the fourth power of the spatial resolution distance, ϵ (assuming the beam height is maintained at a constant multiple of ϵ). It is difficult to know what Gordon meant by "much closer," but for the sake of illustration let us assume that he meant only one order of magnitude out of the possible seven. Then, even ignoring any detector-size limitations, the fourth-power law says that we must increase the patient dose by four orders of magnitude to maintain the same density discrimination. Unfortunately, a similar analysis has not been carried out for nonlinear algorithms, but it appears to us highly improbable that nonlinear methods could make up for this factor of 10^{-4} in the number of detected quanta. Compared with linear processing algorithms, our estimate is that nonlinear methods might afford an advantage of a factor of two or so in resolution for the same density discrimination and patient dose. For the same spatial resolution, this would correspond to a dose reduction of between eight and sixteen times, depending upon whether the beam height is scaled with the resolution distance. It could be argued that this where the potential benefit of nonlinear methods really lies, that is, in reducing dose rather than in improving the resolution.

References

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Correction

December 1977, page 70–In the obituary of Manuel Sandoval Vallarta, the 13th and 14th lines of the second paragraph should read: "... the intensity of cosmic rays observed along 'allowed directions' is equal to that at infinity ..." □