NPSS who need assistance in changing career direction are also eligible for this grant. The grant is for $500 to attend the 2008 NSREC Short Course in Tucson, Arizona, in July 2008.

Nomination forms are available electronically at www.nsrec.com/steeringcommittee. The completed forms must be submitted to the RESG Member-at-Large, Marty Shaneyfelt, at shaneymr@sandia.gov by March 15, 2008. Marty can be contacted at 505-844-6137.

ARTICLES

RADIOLOGICAL IMAGING TO THE THIRD DEGREE

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(http://www.unb.ca/ME/faculty/hussein.html)

Esam Hussein

The common methods of radiological imaging (radiography, computed tomography and emission tomography) have always struck me as not being natural means for imaging. A visual image is formed by the reflection of light from the viewed object to the eye, i.e., the radiation source (light) and the detector (eyes) are on the same side of the object. On the other hand, radiographic and tomographic images are generated by transmitted-through radiation, with the source and detector placed at opposite sides of the object. In emission imaging, radiation can be detected at one side of the object, but then the radiation source is embedded within the interrogated medium; an intrusive process, unlike the passive form of natural vision.

Penetration of radiation, needed to image internal details, can also be realized by the scattering of radiation. This imaging process resembles natural vision, and can be accomplished with the source and detector placed on the same side of the object (i.e., by backscattering). One can then see through matter with radiation “eyes”, and examine large and extended structures, such as solid walls and floors, where radiation cannot penetrate from one side to the opposite side, and without the need for internal sources. Why do not we then commonly see scatterographs? The answer is simple: because scatter imaging is a third-degree interrogation process! Let me elaborate.

When a radiation beam passes through matter, its intensity is attenuated by scattering and absorption. In the transmission imaging of radiography and computed tomography (CT), the intensity of radiation that survives this attenuation process is recorded. Therefore, a transmission measurement is a first-degree measurement, because it monitors only one factor: the attenuation of radiation as it traverses through the object from the source to the detector, as schematically shown in Figure 1. The challenge is then to keep transmission measurements from being contaminated by the higher order effects of scattering and secondary emissions (resulting from radiation absorption). These are non-localized effects that interfere with the extraction of image information along the path of the monitored radiation.

In emission imaging, such as SPECT and PET, the source of radiation is present within the interrogated object, as schematically shown in Figure 1. As such, emission measurements are second-degree measurements, because each measurement depends on two parameters: the intensity of the internal source (the parameter which formulates the image), and the attenuation of radiation from the source to the detector (an intruding parameter that needs to be corrected for). However, emission imaging can be approximated to a first-degree imaging process, by ignoring attenuation. Even then, the emission signal has to be protected from the higher contaminating effects of scattering and secondary emissions.

In scatter imaging, as schematically shown in Figure 1, each measurement is affected by three parameters: attenuation before scattering, the macroscopic scattering cross-section at the scattering point, and attenuation after scattering. The higher order contaminating effects are then the subsequent multiple scattering of radiation and secondary emissions. This is a three-parameter interrogation

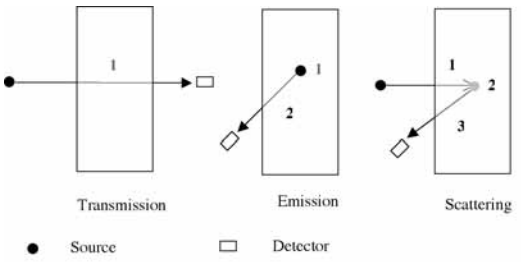

Figure 1: Schematics showing the passage of one source-ray in various imaging modalities.

process, as it can provide images of the two attenuation coefficients (total cross-sections) of the incident and scattered radiation (called here μ_t and μ'_t, respectively), and the scattering cross-section, μ_s. With scatter imaging, one has then in effect a dual-energy tomograph, with μ_t giving an image at the incident energy, and μ'_t providing another image at the scattering energy. In addition, one also has a scatter image through μ_s. The images for μ_t and μ'_t are like those of transmission, because they have to be reconstructed from integrated signals, formed by radiation travel from the source to the scattering point, and away from it. On the other hand, the μ_s image is differential in nature, owing to its reliance on scattering at segregated points in the investigated object. In terms of spatial resolution and material contrast, the transmission-like and scatter images complement each other; the information concealed by the integral nature of transmission is revealed by the differential nature of scattering, and vice versa.

The triplex nature of scatter imaging makes it able to reveal more than one physical attribute at each voxel in the image. To demonstrate this, let us consider imaging with the photons within an energy range where photoelectric absorption and Compton scattering are the dominant interactions, as it is the case for photons emitted from most x-ray machines or radioisotopes. Then the reconstructed cross-sections can be expressed as:

$$\mu_t = (\sigma_s + \sigma_a)\frac{\rho}{Au} = (Z\sigma_e + aZ^m)\frac{\rho}{Au} \qquad (1)$$

$$\mu_s = \sigma_s\frac{\rho}{Au} = Z\sigma_e\frac{\rho}{Au} \qquad (2)$$

$$\mu'_t = (\sigma'_s + \sigma'_a)\frac{\rho}{Au} = (Z\sigma'_e + a'Z^{m'})\frac{\rho}{Au} \qquad (3)$$

where σ_s and σ'_s are the scattering (Compton) microscopic cross sections at the incident and scattered photon energy, respectively, σ_e and σ'_e are the corresponding values per electron, σ_a and σ'_a are absorption microscopic cross-sections at the two energies, respectively, which are related to the atomic number Z by the proportionality constants a and a', respectively, and by the indices m and m', ρ is the mass density, A is the mass number, and u is atomic mass unit.

In conventional transmission tomography, μ_t is reconstructed, while in dual energy CT both μ_t and μ'_t are obtained, and their ratio is used as a composition (by Z) indicator. Scatter imaging indications can be used similarly, or by combining the attenuation-in indication of Eq. (1) with the scattering indication of Eq. (2) to obtain Z. Since for most materials, $\frac{Z}{A} \simeq \frac{1}{2}$, Eq. (3) can be used to independently estimate the mass density, ρ. This estimated value of ρ should then match those evaluated using Eqs. (1) and (2), and if not, a new estimate for ρ that best provides this matching can be obtained, leading to a new estimate for ρ from Eq. (3). The process is repeated until consistent values are obtained for ρ and A. That is, with scatter imaging, one can obtain at each voxel, the mass density and the equivalent mass and atomic numbers of the material within the voxel, which are more affirmative composition indicators than those obtained by dual-energy transmission tomography.

Other obvious advantages of scatter imaging, compared to transmission imaging, are the flexibility in locating the source and the detector, which do not have to be on opposite sides, the ability to use more than one detector for the same radiation source beam, and the three-dimensional nature of the scattering process which makes it amenable to multi-planar imaging. In spite of all the above attractive features of scatter imaging, it faces considerable physical and mathematical hurdles [1]. Deciphering information by visually observing raw scatter radiographs, or a set of measurements, is not directly possible, due the convoluted nature of scatter indications. The problem is caused by the non-localized diffused nature of scattering; although we examined the use of the coded-aperture technique to detect localized anomalies with backscatter imaging [2].

The diffusivity of scattering can be over-

A little knowledge is ....

It is impossible for a man to begin to learn what he thinks he knows.

Epictetus

Closed mind

If you shut your door to all errors, truth will be shut out.

Rabindranath Tagore

come by monitoring only single-scatter events, via radiation collimation or by making use of the unique energy-angle relationship of the kinematics of corpuscular collisions. Even then, single collisions can take place at many locations and mathematical inversion becomes necessary to construct an intelligible image from measurements. The mathematical problem is nonlinear, because the intensity of the scattering signal increases with density and decreases with attenuation. As a result, each recorded scattering measurement corresponds to two possible states: one at low density where scattering is dominant and the other at high density when attenuation prevails.

It is possible, however, to limit the solution to the domain of scatter dominance by restricting the size of the interrogated object to a volume equivalent to that formed by a mean-free-path of the incident radiation. One then assures uniqueness of solution, and the nonlinearity of the problem can be overcome iteratively, as we have done for neutron [3] and gamma-ray imaging [4]. The one mean-free-path restriction limits the use of scatter imaging to a depth of about 150 mm of water-equivalent thickens for 1.25 MeV (^{60}Co) photons and 100 mm for 14 MeV neutrons; two energies at the high end of common radiation sources.

Need somewhere to go

Consistency is the last refuge of the unimaginative.

Oscar Wilde

In effort to extend the imaging depth of scatter imaging while removing the duality of solution, we considered eliminating the effect of scattering and of one of the associated attenuation terms. This was done by taking the ratio of two measurements, in which either the paths of incident radiation overlap [5], or the paths of detected radiation coincide [6]. Then the image reconstruction problem becomes equivalent to that of transmission, where a solution for attenuation factors is obtained. However, once this factor is determined, solution for the other attenuation factor and the scattering cross-section becomes possible. An alternative approach is to use attenuation coefficients readily available from transmission tomography to obtain a unique solution for the scattering cross-section [7]. We have also developed a scheme to bias the solution to the domain of attenuation dominance to image pallet-size cargo shipments [8].

Figure 2 shows a recently acquired image with backscattering using the method of [6], for 5×10 mm^2 pixels. The results of image reconstruction are not as crisp and fine as those observed in CT medical imaging. However, scatter imaging, even at the current state-of-the-art, can be useful in one-side bulk-defect imaging, particularly when only one-side access is available or the object is too thick to allow transmission-through imaging. Examples include: the detection of coke build-up in large diameter pipes, finding holes in refectory liners within tanks and vessels, and examining guide trays and supports inside tanks

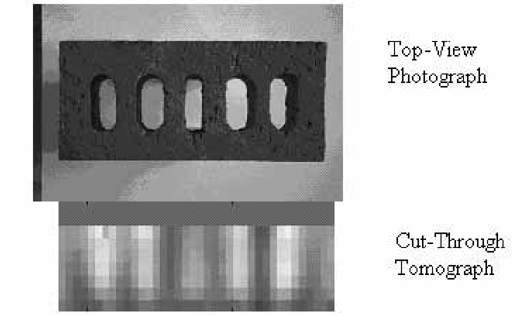

Figure 2: An electron-density reconstructed tomograph of the middle cross-section of a hollow clay brick (top view shown in a photograph). Measurements were acquired by scanning the object from its front (solid) side with a ^{137}Cs source and detecting backscattered photons at 876 positions and orientations. The image was reconstructed over 12x8 pixels (5x10 mm^2 each) using the method of [5], which requires the material at the back of the imaged object to be assigned some known density (methods to remove this restriction are currently under development). This brick was chosen to emulate deteriorated refractory lining (Courtesy of Inversa Systems Ltd., www.inversasystems.com).

It is obvious that the potential of scatter imaging and its powerful features are not fully exploited. I summarized in the above the merits and obstacles of scatter imaging in the hope of encouraging more research in this last frontier of imaging with radiation. Addressing this problem will also benefit the other third-degree imaging process: imaging with induced emission (e.g., by neutron activation), which has three associated parameters -- attenuation of incident radiation, that of emitted radiation, and the activation cross-section (with its elemental discrimination ability).

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Professor Hussein's intrigue with radiation interactions has led him to writing a textbook:

Radiation Mechanics: Principles & Practice
Esam Hussein, University of New Brunswick, Fredericton, NB Canada
Elsevier Science, Oxford, 2007.
(ISBN-13: 978-0-08-045053-7, ISBN-10: 0-08-045053-9)

The publisher's link to the book is: http://www.elsevier.com/wps/find/bookdescription.cws_home/712864/description#description

A short description and a detailed table of contents is on http://www.unb.ca/ME/research/LTMD/RadMech_Outline.html

This book presents a systematic and comprehensive analysis for the radiation interaction mechanisms, their kinematics and probabilities (cross sections), as well as their collective movement (transport). The more than 30 ways via which radiation can interact with the constituents of matter, and its fields, are discussed, in accordance with the nature of interaction mechanism.

Interaction kinematics are analyzed, supported with calculation algorithms, using relativistic (Einsteinian) and classical (Newtonian) mechanics, as well as the powerful concept of invariants. The quantum mechanical and electrodynamics foundations of the interaction cross-sections are examined in a straightforward manner that enables understanding of their behavior, without being immersed in detailed and complex manipulations. The radiation transport process and its associated computational methods are covered in a manner that emphasizes the important features of each approach.

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The selfish gene

When we are planning for posterity, we ought to remember that virtue is not hereditary.

Thomas Paine

Closer to home

Instead of loving your enemies, treat your friends a little better.

Ed Howe

Ed. note: The following is taken from a series of slides related to the Humanitarian Technology Challenge (HTC), a new partnership between IEEE and the United Nations Foundation to identify relevant technological challenges that humanitarian aid workers face in the field and then tap into the innovation and solution-building capacity of IEEE's members to provide focused solutions to all or some of the challenges. The HTC Kick-Off Conference scheduled for 2008 will bring together representatives from Non-Governmental Organizations (NGOs), IEEE Members and Volunteers, Corporations, Philanthropic Foundations and User Gateway NGOs (organizations that can help implement the solutions) to set the challenges and the approaches to solving the challenges. This is only a sampling of the slides presented to our society presidents, but will give you an introduction and some insight into this important activity

Many of the activities planned also relate to the very important work of the broader organization, **Engineers Without Borders**, *the engineering analog to* **Doctors Without Borders**, *the recipients of the 1999 Nobel Peace prize. You can read more about both their US and international activities at http://www.ewb-usa.org/ or http://www.ewb-international.org/, respectively, or contact Prof. Bernard Amadei, EWB-I Executive Director, E-mail: amadei@colorado.edu, Tel:1-303-929-8167. The NPSS liaison to the IEEE-UN Humanitarian Technology challenge is Ray Larsen, larsen@slac.stanford.edu or +1 650 926-4907.*

Humanitarian Technology Challenge

A collaboration between the IEEE and the UN Foundation

November 2007

Russ Lefevre, Chair, TAB New Technology Directions Committee
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