A Scatter Model for Use in Measuring Volumetric Mammographic Breast Density

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Abstract. In order that accurate measurements of volumetric breast density may be made, a model of the scattered radiation present within an image is required: such a model is presented here. The model has the advantageous property of utilising a model of photon scattering, allowing cross sections to be calculated, and thus allowing scatter to be modelled for any object. An analysis is presented which uses the model to quantify the effect of varying small angle scattering properties of breast tissues; and the effect of the height within the breast at which tissues are present. Since the details of the anatomical structure of the breast under measurement are unknown, their precise effect on scatter cannot be calculated, but this model is used here to establish error bounds on the scatter estimate, which is a significant contribution to the error in breast density measurement.

1 Introduction

The study of the correlation between radiological features of the breast and the likelihood of the breast containing, or subsequently developing, a malignant lesion, is termed breast density. In particular, volumetric measurement techniques calculate the quantities of fibroglandular and adipose tissue present in the cone between a detector pixel, and the x-ray focal spot, using the x-ray attenuation coefficients of these tissues. Highnam and Brady [1] originally pioneered the h_{int} representation which utilises this technique to produce a normalised image of anatomical structure. Over recent years, a second generation of this model has been developed which harnesses the extra power made available by modern computers to remove several of the simplifying assumptions made in the original model. Features of the enhanced model include: a ray tracing architecture, removing the parallel beam approximation; consideration of self-filtration within the tube target to model spatial inhomogeneity of the x-ray beam; a theoretical scatter model removing the need for interpolation from empirical data; and a enhanced detector calibration procedure.

We present here an overview of the novel scatter model, and an analysis gleaned through use of the model of the effect on scatter of two properties of the breast.

Two scattering phenomena occur within the breast: coherent (Rayleigh) and incoherent (Compton). Coherent scattering is elastic and involves the energy of the x-ray photon being completely absorbed and subsequently re-emitted in a random direction

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by an electron of a single atom. Incoherent scattering is inelastic, and occurs when a x-ray photon collides with one of the outer shell electrons of an atom. The outer shell electron is bound to the atom with very little energy, and essentially all of the energy lost by the x-ray photon in the collision is transferred as kinetic energy to the electron, which as a result is ejected from the atom. Energy and momentum are conserved in the collision, so the resulting energy and direction of the photon depends on the energy transferred to the electron. In the mammographic energy range, coherent scattering is dominant at low photon energies, whilst incoherent phenomena become steadily dominant as energy increase. High energy photons are present in increased numbers in the spectra employed in clinical use, and so the majority of scatter is incoherent.

The variation in electron density across a molecule resulting from the bonding between constituent atoms provides a significant contribution to the scattering characteristics of photons undergoing coherent phenomena. Variations in molecular bonding therefore manifest themselves within the scattering characteristics, particularly at small angles. Incoherent scatter, resulting from a different physical phenomena, does not exhibit such variation, and is largely independent of molecular bonding. Significant differences in small-angle (3° to 10°) coherent scattering patterns measured from thin excised breast tissue samples have been found. A study by Kidane et al [2] catalogued scattering signatures for 100 excised tissue samples for which histological analysis was available, and found the signature to be useful in differentiating healthy, benign and malignant breast tissue. They reported that shapes of the scatter signatures were “significantly different” between the various tissue types, and hence concluded that “if particular values of momentum transfer are monitored, a discriminating signal could be obtained”. The effect of varying small angle scattering properties of the tissues within the breast, on the total scattered radiation present within a mammographic image, is therefore considered in this paper.

The second property under investigation is the effect of the vertical position of tissue structures within the breast in the plane perpendicular to the detector. The details of both properties investigated are unknown for a breast under examination, and so the analysis in this paper allows the limitations of the scatter model to be established, and thereby the accuracy of subsequent measurements.

2 Overview of the Scatter Model

The cross-section describing the coherent scatter incident on a Cartesian area element (an image pixel) is given in equation 1. For reasons of space we consider only coherent scatter, although a similar relation to that in equation 1 exists in the incoherent case, and the remaining algorithmic details are equally applicable.

$$\sigma_{coherent,pixel} = \int_{y_1}^{y_2} \int_{x_1}^{x_2} \frac{r_e^2}{2}\left(1+\cos^2\phi\right) F_m^2\left(\frac{\sin\phi}{\lambda}\right)\frac{c}{r^3}\,dx\,dy \qquad (1)$$

The scatter model uses equation 1 to calculate the cross section describing the scatter originating from each infinitesimally small traversal of the primary beam, destined, subject to further interaction, for each of the image receptor pixels in the