Robustness of phase-retrieval from a single x-ray image

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Retrieval of the tissue phase-map, a map of tissue projected electron densities, has great potential for improving tissue contrast and achieving quantitative imaging for tissue characterization. The robustness of a phase-retrieval approach is of critical importance for clinical imaging applications. On the one hand, the limits on permissible organ radiation doses make acquired images much noisier than that encountered in other non-clinical applications. On the other hand, the phase changes of pathological tissues are small and the diagnosis accuracy would be very much vulnerable to the phase-retrieval errors. For example, while a 4cm-thick breast tissue generates about 700 radians, the phase-shift difference between a 5mm-size invasive ductal carcinoma in the breast and surrounding breast parenchyma is of only about 5 radians for 60 keV x-rays. In this presentation the robustness of phase-retrieval from a single image based on the phase-attenuation duality is compared to its performance with that with the popular Transport of Intensity Equation (TIE) based phase-retrieval approaches for 60-keV x-rays by means of computer simulations. The imaged object is a hypothetical breast of 4 cm thick with very low tissue radiographic attenuation contrasts $\leq$ 0.83% for 60 keV x-ray, this attenuation contrast corresponds to that between a 5mm-size invasive ductal carcinoma and surrounding normal breast parenchyma. For the single phase-contrast image acquisition the source to breast distance was set to 1m and the breast-detector distance all were all set to1m. The x-ray Fresnel diffraction was simulated for the formation of the breast phase-contrast image. Moreover we assumed a quantum noise 5% associated with the image acquisitions. With this single phase-contrast image the breast phase-map was retrieved with an average relative phase-error of 0.11%. For the TIE-based phase retrieval approach, an additional image acquired at the contact mode with an anti-scatter grid was simulated. This contact-mode image is the attenuation image of the breast with a quantum noise of 5% as well. With these two images (one attenuation image and one phase-contrast image) the breast phase-map was retrieved by the TIE-based approach. Since the TIE-based phase-retrieval suffers from intrinsic instability due to the low-frequency noise-amplification, the regularization techniques such as the Tikhonov regularization was employed. The Tikhonov regularization seeks the minimum-norm, least squares solution for phase-retrieval. In spite of increased radiation dose to breast (due to two acquired images needed) TIE-based phase-retrieval still suffers from loss of phase-retrieval accuracy. The average relative phase-error with the TIE-retrieved breast phase-map is 0.91%, compared to that of 0.11% for the duality-based phase retrieval. In addition, the areas suffering from distorted tissue-contrast in the TIE-retrieved breast phase map is prominent. Hence the phase-attenuation duality-based approach is superior to TIE-based approaches for tissue phase retrieval with hard x-rays of about 60 keV or higher. Finally we discuss how this phase retrieval approach facilitates the tomographic reconstruction of a 3-D map of tissue electron densities as well.