Low Order Geometric Models for Ill-Posed Imaging Problems

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Problems of image formation arise in a wide range of fields including medicine and biology, earth and materials sciences with applications including disease diagnosis, drug development, environmental remediation, global climate change, energy, security, and nondestructive evaluation. In all of these cases, the objective of the problem is, at a high level, to characterize the distribution of some physical quantity (or quantities) in a region of space from indirect observations. X-ray tomography, magnetic resonance imaging, and diagnostic ultrasound are perhaps the best known examples of such problems. In many instances however, the combination of the sensing physics and restrictions on where data can be collected conspire to make image formation rather challenging in that the ability to recover high resolution images is greatly impeded by the sensitivity of the reconstruction process to noise in the data and un-modeled physics.

To overcome these difficulties we take advantage of the fact that, for many problems, the ultimate processing objective is the identification of spatially homogeneous anomalies such as tumors, cracks, pollution plumes, etc. existing against a perhaps unknown background. The problem then becomes one of identifying the geometry and contrast of these objects as well as some information regarding the background medium. In this talk I shall discuss the challenges associated with such a geometric approach to image formation as well as a new model-based technique for stably recovering much higher resolution information than is commonly thought possible. The method is based on a level set representation of the geometry where and makes use of low-order parametric basis functions for representing the unknown level set function.

The performance of the approach will be discussed in the context of two problems. The first comes from the field of groundwater hydrology and involves the identification of the structure of subsurface zones of chlorinated solvent contamination from observations of contaminant concentration and electrical resistance tomography data. The second application is in the field of diffuse optical tomography in which near infrared light is used as the basis for mapping concentrations of oxygenated and deoxygenated haemoglobin as well as lipids and water to detect breast cancers. Of particular interest here is the use of a hyper-spectral data set.

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