Photoacoustic Sectional Imaging and Reconstruction Formulas for a Single Scattering Model

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We consider photoacoustic sectional imaging experiments. Opposed to standard photoacoustic imaging (see e.g. [9, 8, 6, 10] for some mathematical and physical review papers), where the detectors record sets of two-dimensional projection data over time, from which the three-dimensional imaging data can be reconstructed, in sectional imaging, a single scan procedure is implemented to be able to reconstruct a set of two-dimensional slice imaging data. The advantages of the latter approach are a considerable increase in measurement efficiency and the possibility to perform selective plane imaging. However, the disadvantage is a decreased out-of-plane resolution (i.e. the direction orthogonal to the focusing plane). Experimentally, one can realize photoacoustic sectional imaging with pulsed laser illuminations focusing to a single plane and with focusing detectors for the measurement of the pressure wave [7].

Analogously to standard quantitative photoacoustic imaging we observe two decoupled reconstruction problems:

(1) The inverse acoustic problem of recovering the initial pressure in the illuminated slice from the two-dimensional measurements of the pressure wave and
(2) the inverse optical problem of reconstructing the absorption coefficient from this initial pressure data, which is assumed to be proportional to the absorption coefficient and to the light fluence of the laser pulse.

For the acoustic problem, we model the propagation of the pressure wave by the linear three-dimensional wave equation and derive explicit reconstruction formulas for the initial pressure distribution for various detector geometries (including point, line, and plane shaped detectors placed around the object). In particular for line detectors in the illumination plane and vertical plane detectors, exact reconstruction formulas for an arbitrary placement of these detectors around the object are available [4]. Moreover, these photoacoustic sectional measurements allow for a simultaneous reconstruction of an unknown speed of sound if measurements for all possible slices through the object are performed [5].

For the optical problem, we assume (in accordance with the focused illumination of only one slice) that scattering effects are sufficiently weak so that a single scattering model for the light propagation of the illuminating laser beam is practible. This is different to recent approaches in standard quantitative photoacoustic imaging [1, 2] where the scattering is typically assumed to be so large that a diffusion approximation model for the light propagation can be used. In this sectional imaging approach, however, the scattering in the object should be rather small, since a localisation of the illumination is otherwise not possible. Nevertheless, our reconstruction formulas for the single scattering approach rely on a similar strategy as in the diffusion approximation and are based on deriving equations for quotients of independent measurement data obtained from measurements for two different laser illuminations (e.g. from two opposing directions) [3].

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