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Light Refractive Tomography for Noninvasive Ultrasound Measurements in Various Media

Currently, hydrophones are routinely used in ultrasound measurements in water. In spite of their high measurement accuracy and the possibility of measuring high frequency ultrasound (e.g., f = 20 MHz), hydrophones always suffer from the sound diffraction induced by the immersed hydrophone itself as well as the dependency of the output response on the angle of incidence. Since the discovery of acousto-optic interaction, optical techniques are expected to achieve accurate ultrasound measurements and avoid these two limitations, because light can retrieve information about ultrasound without material contact.

Light refractive tomography (LRT), which utilizes laser light to detect ultrasound pressure in fluids, has long been underestimated as a simplification of another optical technique, light diffraction tomography (LDT). After a thorough review of published research, it appears that LRT is so far the sole technique, which is noninvasive, omnidirectional and provides time-resolved results scaled in Pa. In the process of developing LRT into a reliable and useful ultrasound measurement technique, achievements have been made in four different aspects:

- Accuracy: With the aid of numerical simulations, potential systematic errors are quantitatively analyzed. The subsequent development of simple and effective methods ensures that critical error sources have small influences on results (typically < 1%). The total uncertainty of LRT measurement in water is typically below 15%, similar to the one of LDT.
- Efficiency: LRT is especially effective in reconstructing ultrasound fields in different cross sections. After the optimization of the measurement procedure, the LRT measurement of ultrasound pressure in one cross section with a spatial resolution of 0.2 mm requires less than 1 h, while a corresponding hydrophone measurement needs about 12 h.
- Applicability: Based on the measurement setup developed in this work, LRT is able to reconstruct ultrasound fields arising from arbitrarily-shaped transducers. Furthermore, LRT has a constant output response to different ultrasound frequencies, and its noninvasive nature enables measurements of high-intensity pressure fields without risk of damaging instruments. Finally, acousto-optic interaction exists in liquids, gases and solids.
- Distinction: LRT shows excellent suitability for ultrasound investigations in the presence of media boundaries, which may cause considerable sound reflections. Several measurements are demonstrated, which are nearly impossible by means of other techniques, e.g., the measurement of a disturbed pressure field in a conventional hydrophone measurement and the reconstruction of ultrasound fields throughout water and Poly(methyl methacrylate) (PMMA). Moreover, in case of high-intensity ultrasound, LRT avoids to provide any additional cavitation nuclei. Accordingly, LRT measurements possess higher repeatability than hydrophone measurements.

The thesis begins with an overview of measurement principles and underlying mathematics. Afterwards, the measurement procedures are described in detail, which include building LRT experimental setups, choosing measurement parameters, minimiz ing systematic errors, executing measurements and analyzing results. The advantages and disadvantages of LRT are presented by demonstrating experiments, which are accomplished for different research purposes. For instances, LRT is applied to measurements of ultrasound fields in water, air, PMMA. Furthermore, LRT provides reasonable measurement results about high-intensity ultrasound fields (pressure amplitude > 1MPa) arising from an ultrasound device driven by compressed air. Finally, the conclusion is drawn and some further research possibilities are suggested.