Experimental application of high precision k-space filters and stopping rules for fully automated near-field acoustical holography

Rick Scholte, Ines Lopez

Department of Mechanical Engineering, Technische Universiteit Eindhoven, P.O. Box 513, 5600 MD Eindhoven, The Netherlands

N.Bert Roozen

Department of Mechanical Engineering, Technische Universiteit Eindhoven, P.O. Box 513, 5600 MD Eindhoven, The Netherlands
Philips Applied Technologies, Eindhoven, The Netherlands

Henk Nijmeijer

Department of Mechanical Engineering, Technische Universiteit Eindhoven, P.O. Box 513, 5600 MD Eindhoven, The Netherlands

(Received 9 June 2008; accepted 17 July 2008)

In general, inverse acoustics problems are ill-posed. Without proper regularization action taken, noisy measurements result in an increasingly disturbed solution of the inverse acoustics wave equation as the distance from the measurement plane to the desired source grows. Two distinctive steps take place in the regularization process for planar near-field acoustical holography (PNAH): first, a low-pass filter function is defined and secondly a stopping rule is applied to determine the parameter settings of the filter. In acoustical imaging practice, it turns out to be very hard to determine the right filter for a certain case, ideally by means of an automatic search for the (near-) optimal parameters. This paper presents the practical application of a novel automated method that combines fitted filters for a broad number of possible experimental sources combined with highly efficient stopping rules by taking advantage of k-space. Also, a number of well-known and newly developed filter functions and stopping rules are discussed and compared with one another. Results based on actual measurements demonstrate the effectiveness, applicability, and precision of the fully implemented and automated regularization process for PNAH. Practical results even show acoustic source visualization below one millimeter primarily by successful application of k-space regularization. Implementations include modifications of Tikhonov, exponential and truncation low-pass filters, L-curve, Generalised Cross-Validation (GCV) and the novel Cut-Off and Slope (COS) parameter selection methods for PNAH. COS iteration in combination with either a modified exponential or Tikhonov low-pass filter results in an automated selection of the regularization parameters and eventually a fully automated PNAH system.

1. INTRODUCTION

Near-field acoustical holography (NAH) dates back to the early 1980s when Williams[1] suggested that a large portion of source information is available in the near-field of a sound source. NAH potentially results in spatial acoustical resolutions far beyond the wavenumber resolution limit of beamforming or acoustical holography.[2] In the near-field, evanescent waves attenuate with an exponential power as a function of distance from the sound source while propagating waves primarily shift in phase. To detect evanescent waves, a fine grid of measurement positions is required at a fixed distance from the source, yet within the near-field. The acquired field information is called a hologram, which contains all necessary information required to identify the sound source. Source information is determined by the calculation of the inverse solution of the wave equation. Noise in the hologram measurements is very susceptible for blow-up in the inverse solution, especially at high wavenumbers. A wide variety of methods to regularize ill-posed problems in general are discussed in Reference[3], whereas more recently References[4,5] focussed on regularization methods for NAH.

This paper briefly discusses the basic PNAH theory, followed by a listing and discussion of regularization in k-space, which is split into filter functions and stopping rules. Next, the measurement set-up and post-processing procedures used are presented. The main focus lies on the practical aspects of automated regularization and the possibilities it offers. One of the advantages is that it takes away the burden of regularization parameter selection from the end-user, and eventually provides the possibility to fully automate the entire inverse acoustics method. The sources examined are two closely spaced holes in a large baffle connected to an isolated speaker at the back. A second case requires a much higher resolution of the acoustical images since three millimetre-sized sources are observed only 0.5 mm apart. The results of the k-space application of five-filter-functions combined with the two general stopping rules, GCV and L-curve, are illustrated. One of the main conclusions emphasises the importance of a variable filter slope, combined with a stopping rule capable of handling two or more filter parameters. The COS iteration method with a modified exponential filter is such an example that demonstrates its effectiveness and accuracy in an automated PNAH measurement system.