Acta Physicae Superficierum · Vol II · 1990

DECONVOLUTIONAL METHODS IN THE RECONSTRUCTION OF LOCAL MATERIAL PARAMETERS

HORST SCHWETLICK

Institut für Allgemeine Elektrotechnik, Technische Universität Berlin, D-1000 Berlin 10, Germany

INTRODUCTION

Deconvolutional methods are used for processing ultrasonic impulse echo signals in order to obtain more detailed quantitative information about material properties and defects. Examples of one-dimensional processing to increase the axial resolution of a single A-scan are given in [1] and two-dimensional deconvolution of C-scan images are presented in [2]. In the methods described in this paper, deconvolution is part of the reconstruction process. For band-limited and noise contaminated data, the deconvolution may provide inaccurate results. In such cases either estimations can be used or procedures utilizing prior information which require greater mathematical and numerical effort [3]. Utilizing the latter in combination with the algorithm given in [4], the impedance profile of a layered medium can be reconstructed in the direction of sound propagation. Multiple reflections are included in the process of reconstruction. The spatial and temporal radiation pattern of the transducer in pulse echo mode is included in the model given in [5]. The reconstruction, based on three-dimensional deconvolution, provides an estimate of the local reflectivity as a function of space, independent of the geometry of the reflector.

DECONVOLUTION AND *A PRIORI* INFORMATION

The ultrasonic echo can be represented as the convolution of an incident wavelet and a reflectivity function of the specimen being tested. Deconvolution represents the inverse problem, which is to determine the reflectivity from known reflection and wavelet data. The computation of the deconvolution is performed numerically from the digitized data. With most available transducers the information of the reflection data is contained in a limited passband. As a result the deconvolution problem may not be well posed. In Fig. 1 the classification of

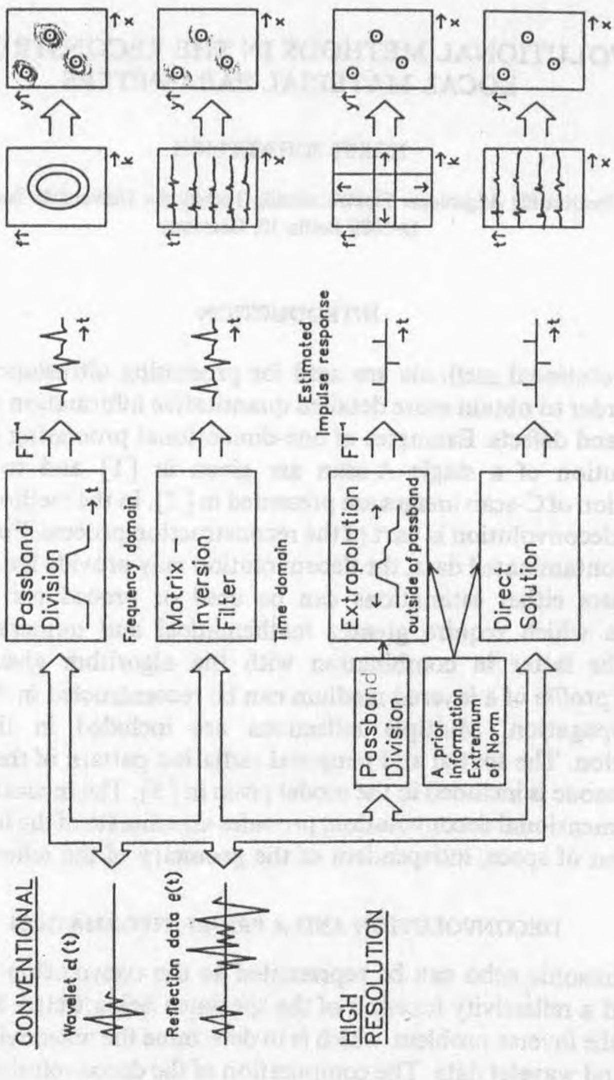

Fig. 1. Deconvolution methods.

methods is given. An estimate of the impulse response can be computed by considering only passband data as it is done by truncation of data outside the passband, by Wiener filtering, and by inverting the convolution matrix. A robust estimate for the impulse response with high resolution and accuracy can be achieved by including prior information in the computation. The solution must fit the data and at the same time minimize or maximize a functional relation representing the *a priori* information. The minimization of the L_1-norm and the maximization of the information entropy have been investigated in this context. Direct, straightforward solutions as well as spectral extrapolation methods are derived from these principles in [3]. All these methods force the solution to have a minimum number of nonzero components and a high resolution. The result in one-dimensional processing is a sparse spike train impulse response and in higher dimensions an image with a small number of points.

RECONSTRUCTION OF A LAYERED MEDIUM

High resolution deconvolution was applied to the reconstruction of the impedance profile of a one-dimensional layered medium from plane wave impulse echo data. The computation was done in two steps. First, an estimate of the impulse response data was obtained by a high resolution deconvolution method. Since the algorithm given in [4] is stable for a non-bandlimited impulse response, the impedance profile was computed in the second step from that impulse response. In the example in Fig 2, ultrasonic reflection data from two acrylic plates in water were analysed. An extrapolation method based on the minimization of the L_1-norm was used to find an impulse response from the reflection data which is non-bandlimited up to the Nyquist frequency. The first layer in the corresponding impedance profile was completely recovered. Toward deeper regions, errors tend to accumulate and reduce the accuracy.

THREE-DIMENSIONAL DECONVOLUTION

Three-dimensional deconvolution based on Wiener filtering was used to obtain qualitative information on a reflecting region. In this approach the echo is considered to be the convolution of the local reflectivity with the spatial and temporal characteristics of the transducer. The reconstruction of the reflectivity can be looked on as the elimination of transducer characteristics by deconvolution which is computed by division in the wavenumber frequency domain. In the example in Fig. 3 the scanned reflection data from an agar (gelatine) surface and an embedded 0.5 mm glass sphere were used to reconstruct the local reflectivity. The result clearly shows the increased amplitude for the solid point reflector.

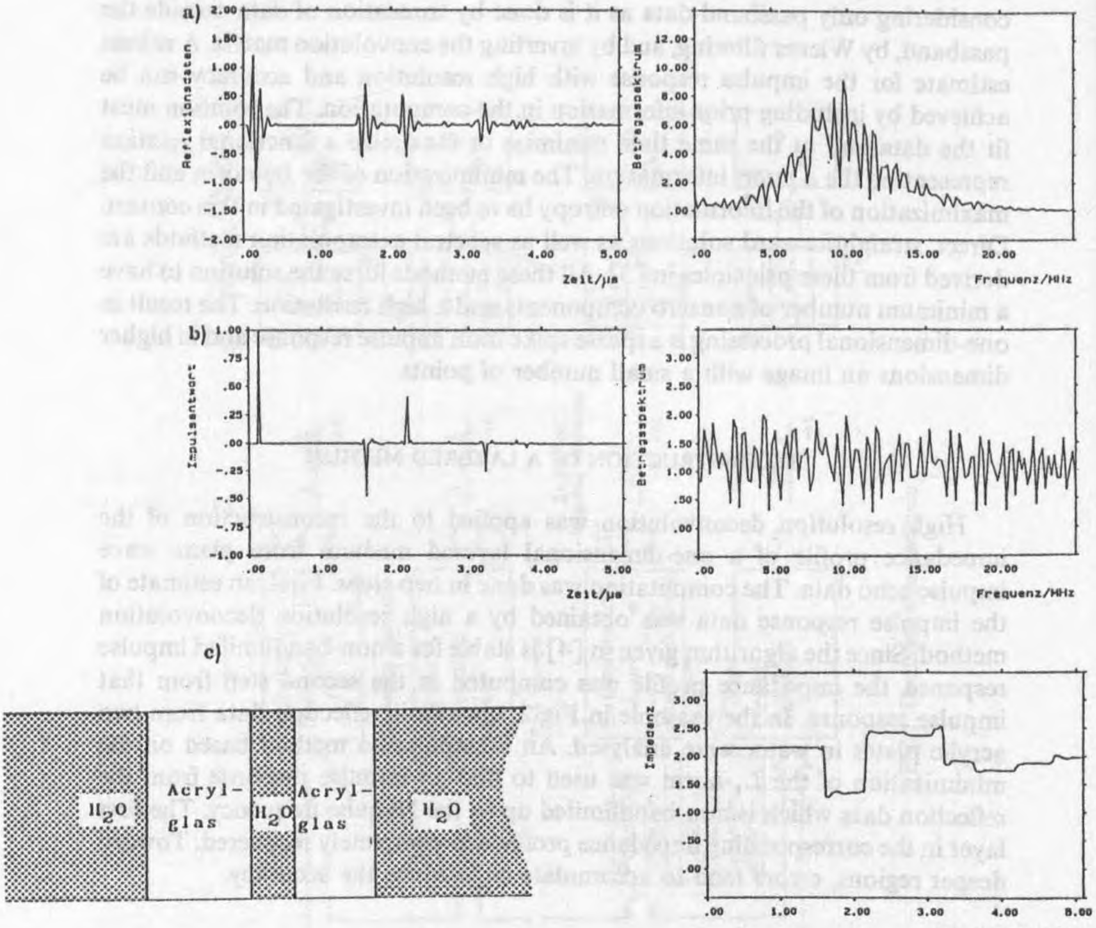

Fig. 2. Reconstruction of a layered medium from impulse echo data: a) measured echo data and corresponding amplitude spectrum; b) estimated impulse response as a result of deconvolution and corresponding spectrum; c) reconstructed impedance profile.

ACKNOWLEDGEMENT

The author would like to thank Prof. J. Kapelewski for initiating this article. The support of the German Alexander von Humboldt-Stiftung, the Japan Society for the Promotion of Science and the FIM Project at TU-Berlin is also gratefully acknowledged.

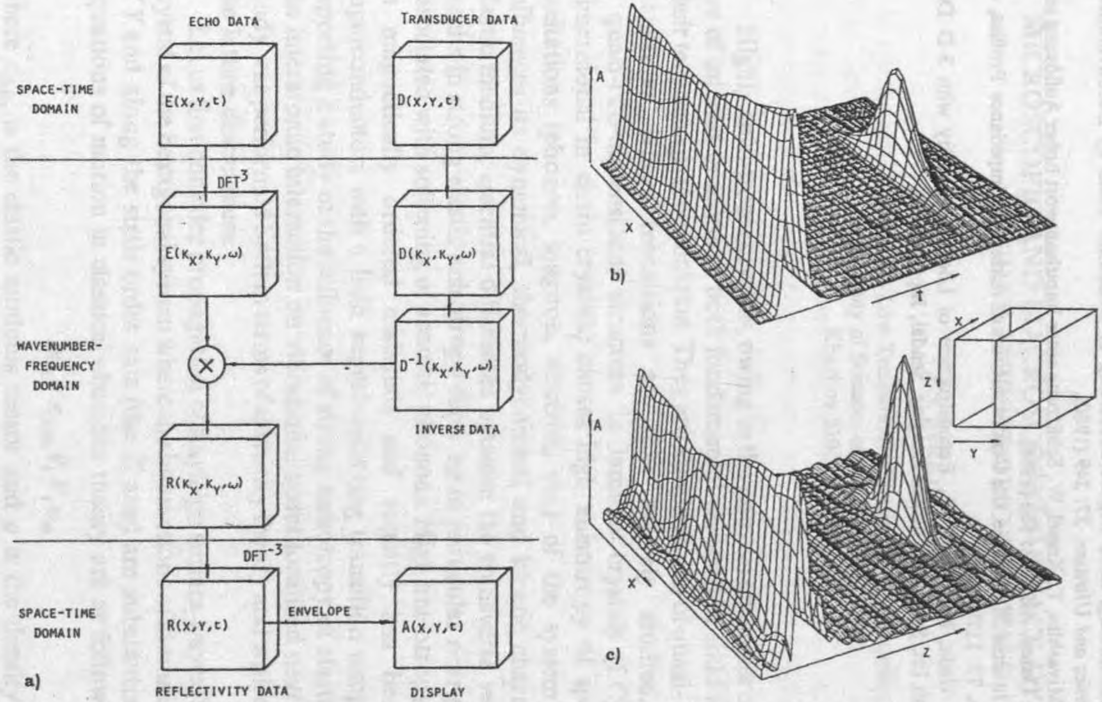

Fig. 3. Reconstruction of a plane and a point reflector from scanned impulse echo data: a) numerical procedure; b) envelope of the measured impulse echo data; c) reconstructed reflectivity.

REFERENCES

[1] Nabel, E., Die Impulsantwort als Ergebnis der Ultraschallspektrometrie, Versuche zur exakten Bewertung von Ultraschallechos, *Materialprüfung* 19: 496 (1977).

[2] Hundt, E.E., Trautenberg, E.A., Digital Processing of Ultrasonic Data by Deconvolution, *IEEE Trans. Sonics and Ultrason.* 27: 249 (1980).

[3] Schwetlick, H., Miyashita, T., Kessel, W., Schätzung einer Impulsantwort hoher Auflösung aus bandbegrenzten Daten, *AEÜ* 42: 160 (1988).

[4] Schwetlick, H., Inverse Methods in the Reconstruction of Acoustical Impedance Profiles, *J. Acoust. Soc. Am.* 73: 1179 (1983).

[5] Schwetlick, H., Ueda, M., Tabei, M., Reconstruction of Local Reflectivity with 3-D Deconvolution, 17th Int. Symp. Acoustical Imaging, Sendai, Japan (1988).