DETERMINING THE ACOUSTICAL PROPERTIES OF AN OBJECT BY PLACING IT IN A RANDOM NOISE FIELD

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Abstract: The acoustical properties of an object are determined by its structural admittance **Ys,** also called the structural Green's function. We develop the theory for determining **Ys** from measurements made when the object is placed in a random noise field and then demonstrate its viability by Monte Carlo Simulation. Finally, we show the results of an experiment for a thick spherical shell that was outfitted with eight collocated microphones and accelerometers. Symmetry based interpolation was used to construct a dense surface grid of data. The structural admittance determined from the data showed excellent agreement with theory. This measurement procedure combined with the earlier formalism of Bobrovnitskii [Acoustical Physics, 52(5), 513-517, 2006] results in an extremely efficient method for determining the scattering properties of an object arbitrarily oriented in a complex, external medium.

Keywords: Scattering, Structural Impedance

1. INTRODUCTION

Identification of unexploded ordinance buried in the sediment in the littoral waters throughout the world is a problem of great concern. When illuminated by low-frequency sonar some of these targets exhibit an elastic response that can be used to identify them. This elastic behavior is embodied and identified by a quantity called the structural admittance matrix Y_S, a relationship between the sonar-induced forces and resulting vibration on its surface. When it is known it can be combined with surface impedances to predict the 3D bistatic scattering in any fluid-like media and for any burial state (depth and orientation). At the heart of this is the measurement of Y_S and we demonstrate in this paper that this can be accomplished by studying the target in a simple (acoustically unaltered) in-air laboratory environment. The target chosen in this study is a thick spherical shell that was illuminated by an nearly spatially isotropic array of remote loudspeakers. The theory of this paper was motivated by the results of Bobrovnitskii[1] and fully developed in [2] with appropriate references contained therein. A detailed description of the experiment and its results are presented in [3].

2. BACKGROUND

According to Ref [1] the scattering properties of an object placed in an external medium can be determined by three quantities, its structural, internal (or incident) and radiation (or acoustics) impedance (or inversely, admittance denoted **Y**) as shown schematically in Fig 1. Clearly, $\mathbf{Z}_i$ and $\mathbf{Z}_a$ can be computed by standard finite element methods whereas $\mathbf{Z}_s$ requires total knowledge of the internal complexity of the object and subsequently requires a very elaborate computation. Alternatively, a full scattering experiment would require multiple source receiver configurations and then, only for a specific orientation of the object in the external medium. The present result avoids this alternative and is based on the idea that a particular type of measurement of $\mathbf{Z}_s$ essentially avoids all these costly and complex procedures.

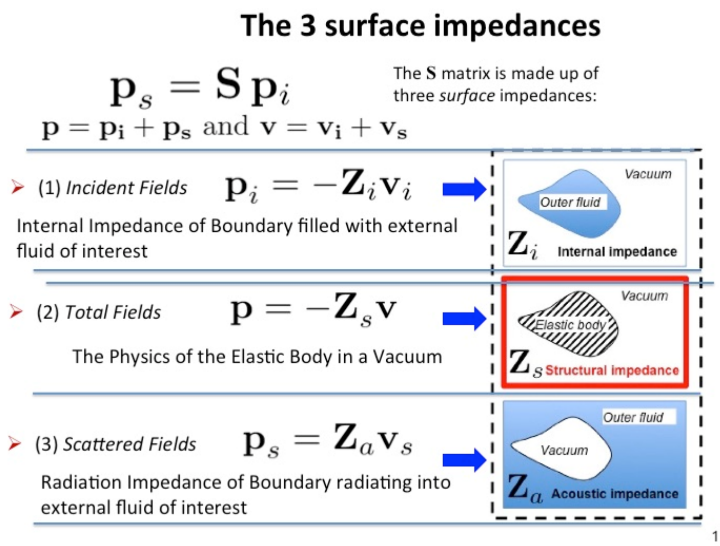

Figure 1: The three impedances that completely describe the acoustic scattering of an object I an external medium.

Reference [2] derived that if an object is immersed in a random noise field, its structural impedance can be determined from,

$$\mathbf{Z_s} = -\langle \mathbf{p}\mathbf{p}^H \rangle \langle \mathbf{v}\mathbf{p}^H \rangle^{-1}$$

where **p** and **v** a vectors of pressure and velocity measurements on the surface of the object immersed in random noise field and the brackets represent averaging over many measurements. Reference [2] derived and subsequently demonstrated this process with a Monte Carlo experiment where as the actually experimental results presented below are given in detail in Ref [3]. We actually work with the inverse of the impedance matrices, admittance matrices $\mathbf{Y}$, that, then essentially determine the velocity at a point on the surface from a force applied to any point on the surface.

3. THE EXPERIMENT

Y_S is constructed from ensemble averages of the cross-correlations of collocated accelerometers and microphones placed over whole the surface of the object that is immersed in a random noise field. Actually, though, we take advantage of spherical symmetry for the purpose of the feasibility experiment. Since only 8 sensor-pairs were available for the experiment, the spacing chosen for the eight sensors was based on a modified Fibonacci series because then the differences between any two spatial points are all unequal, and thus provides a unique ensemble-averaged correlation set for 29 different arc lengths between two sensors, including the drive point and the anti-pole. This simulates a measurement using 29 sensor pairs on a semi-circular arc. These 29 data matrices are then interpolated onto a uniform grid of 250 points on the surface and he scattered field for a particular incident field can then be determined from the top equation in Fig. 1 together with the expression,

$$\mathbf{S} = (\mathbf{Y}_a + \mathbf{Y}_s)^{-1} (\mathbf{Y}_i - \mathbf{Y}_s).$$

4. RESULTS

An example of the results for the structural admittance is shown in Fig. 2. The bottom panel shows the theoretical results using the properties of the shell in an analytic calculation and the upper panel shows the results of the experiment. Figure 3 is an indication of the resulting accuracy of the experiment where the drive point impedance, zero angle in Fig.2, is compared with theory.

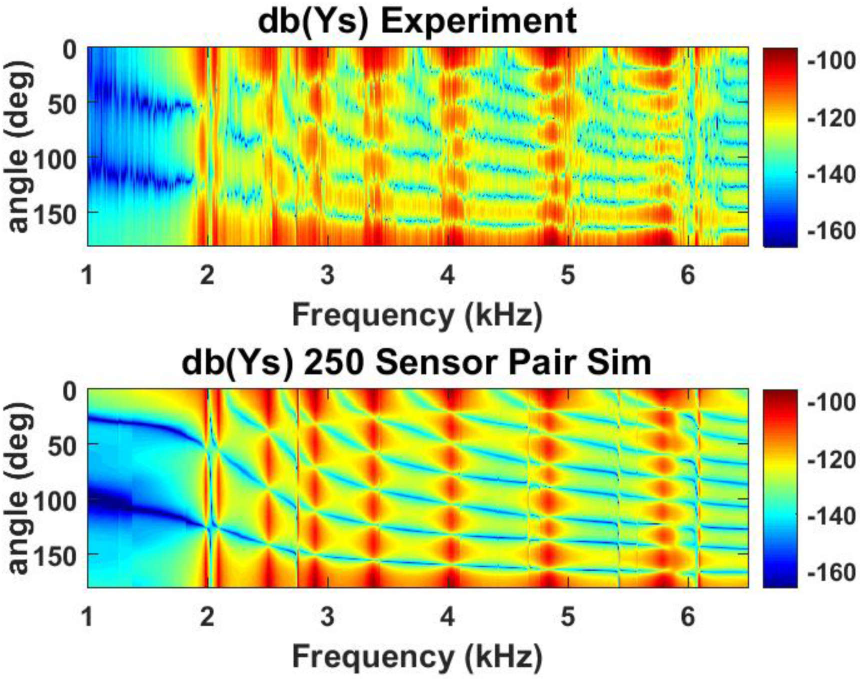

Figure 2: Comparison of experiment and theory.

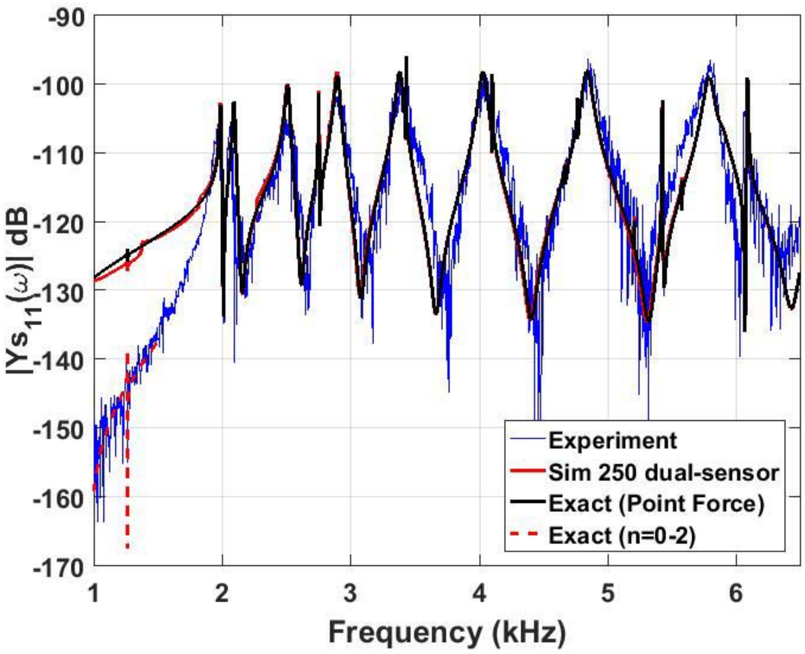

Figure 3. Detailed comparison of results for the drive point admittance (the zero angle results of Fig 2.)., n refers to spherical modes in the theory.

5. SUMMARY AND CONCLUSIONS

We have shown that the structural impedance of an object can be measured using ensonification by a random acoustic field. These particular experimental results relied on spherical symmetry. The next step will be to do the experiment on an object with a more complicated shape using the required additional number of sensors for the measurement.

6. ACKNOWLEDGEMENT

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