RECONSTRUCTION OF ACOUSTIC FIELDS ON A PARTIALLY MASKED SOURCE USING INVERSE PATCH TRANSFER FUNCTION (IPTF) METHOD

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ABSTRACT

The acoustic source localization, reconstruction and ranking is a tedious task in industrial environments. Indeed, the source (for example a pump, an engine) is often of complex shape and partially masked by obstacles like mounting frames. In that case, the use of classical backpropagation techniques using arrays of microphones can be tricky. The aim of the presented works is to illustrate how the inverse Patch Transfer Functions (iPTF) can be used to tackle such a situation. The concept of iPTF is based on the application of Green's identity on any virtually closed volume defined around the source. In addition, it involves the discrete acoustic measurements performed at accessible positions around the source and the numerical computation of virtual volume mode shapes. In the present work, the advantages and limits of this approach are investigated through a parametric study on the simple test case of a simply supported plate masked by a rectangular rigid obstacle in front of it. This parametric study addresses the influence of distance between the structure and the obstacle and of the percentage of masked surface on the quality of the results. Some numerical results will be shown to illustrate the application and robustness of the iPTF in reconstruction of sound source in the presence of obstacle.

1. INTRODUCTION

The source identification in the presence of obstacles is a matter of relevance for industrial applications. In automotive industry, it would be valuable to retrieve the velocity field of a source that is intricately located with other structures partially blocking its accessibility. This situation is mostly encountered in the gearbox and engine compartments of a vehicle. In the present study, a method called "inverse Patch Transfer Function" (iPTF) [1-3] is used to handle this task.

The iPTF method is able to identify the vibration velocity of irregularly shaped sources in a non-controlled acoustic environment (reverberant room, stationary disturbing sources, etc.). The objective of the present work is to demonstrate numerically how to use the iPTF method to identify the velocity field of a source masked by a rigid obstacle. A parametric study is proposed which involves varying geometric dimensions and spatial positons of the obstacle. The remarkable quality of the reconstructed field compared to the reference computation demonstrates the capability of iPTF method to handle the presence of masking obstacles.

2. THEORETICAL BACKGROUND OF THE IPTF METHOD

The following example in Figure 1 gives a brief description of iPTF method. Details of theoretical derivation have been presented in Ref. [3].

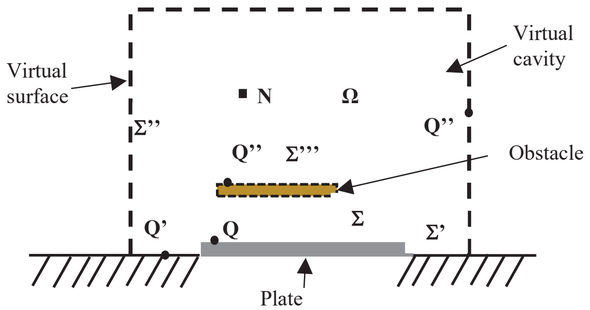


Figure 1. Normal velocity reconstruction of a plate in a noisy environment in the presence of an obstacle

Let assume the source represented by the surface Σ vibrates with a velocity field in a semi-infinite medium. The iPTF method is based on the definition of an arbitrary virtual acoustic cavity surrounding the source to identify (see Figure 1). The virtual acoustic cavity Ω engulfs an obstacle of surface Σ'''. This virtual cavity is thus delimited by the surfaces Σ' (possible rigid surface), Σ'' (virtual surface surrounding the source) and Σ''' with corresponding points Q', Q'' and Q''' (see Figure 1). The acoustic problem is governed, in this acoustic domain, by the Helmholtz equation and corresponding boundary conditions. As detailed in Refs. [1-3], this system of equations can be solved introducing acoustic impedance transfer functions and dividing the surfaces into element surfaces called patches. Therefore, the pressure $p(N)$ at a point N inside the volume can be expressed as

$$p(N) = \sum_{j=1}^{N_m} Z_{Nj}\bar{V}_j + \sum_{l=1}^{N_s} Z_{Nl}\bar{V}_l \,. \qquad (1)$$

The subscripts N, j and l denote respectively a point inside the virtual volume, a patch of the source surface Σ and a patch of the virtual surface Σ''. The terms Z_{Nj} and Z_{Nl} are the acoustic impedances. Equation (1) permits the calculation of the pressure at a point N using the velocities of the patches. For a sake of simplicity, Equation 1 is rewritten under matrix form when handling several points i in the virtual cavity

$$\{P_i\} = [Z_{ij}]\{V_j\} + [Z_{il}]\{V_l\} \,. \qquad (2)$$

The aim of the iPTF method is to identify the source velocities $\{V_l\}$. For that purpose, one uses Equation 2, which after simple matrix manipulation allows the computation of source velocities as

$$\{V_l\} = [Z_{il}]^{-1}\left(\{P_i\} - [Z_{ij}]\{V_j\}\right). \qquad (3)$$

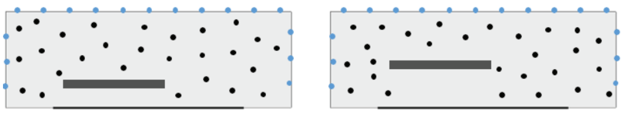
The acoustic patch impedance matrices of the volume defined by surfaces Σ and Σ″ are dependent on the acoustic cavity modes and computed numerically. The eigenmodes are extracted with a standard finite element solver. The pressure and velocity vectors of Equation 2 are measured in the virtual acoustic cavity Ω and on the virtual surface Σ″ respectively. The matrix $[Z_{il}]$ is often ill-conditioned and a regularization technique has to be used to invert it. The solution is found using Tikhonov regularization and the maximum of curvature of the L-curve is used to define the best regularization parameter – e.g. see Refs. [2, 4, 5].

3. NUMERICAL VALIDATION

3.1 Approach

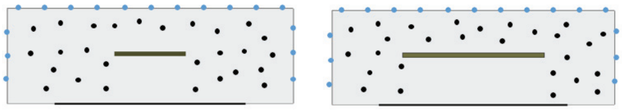
The iPTF method has two main aspects. These are acoustic modes extraction and acoustic measurement. The mode extraction involves the use of a finite element solver. The finite element tool in this case is the ACTRAN software [6]. The acoustic measurement is usually obtained through experimental means but in this study, they are obtained through running acoustic simulation with ACTRAN software. Purely numerical experiments are carried out for the parametric study. For this numerical validation, the identification is performed on a simply supported plate excited by a harmonic point force. The plate is 0.6m long, 0.4m wide, and 2mm thick, and it is made of aluminium (Young's modulus $E = 7.0 \times 10^{10}$ Pa; density ρ =2700 kg/m^3; Poisson's ratio $\nu = 0.35$; damping $\eta = 0.01$). The plate is excited by a unit point force located at point (0.15; 0.15) m on the frequency band [100:1000] Hz with frequency step of 5 Hz.

In the following example, two main configurations are considered for the parametric study. In the first configuration the depths of the obstacle from the source surface are varied as seen in figure 2. The second configuration is shown in figure 3, where the widths of the obstacle across the source at a specific distance are varied. In all these cases, no measurement sensors are located between the obstacle and the plate. The depths considered for the numerical studies are 5cm and 10cm for an obstacle of width 15cm. The widths considered for the numerical studies are 15cm and 30cm for an obstacle placed 10cm away from the vibrating plate. For the sake simplicity, the letter "d" and "w" will represent depth and width of obstacle.



(a) (b)

Figure 2. The 2D YZ view of the spatial distribution of sensors in the virtual acoustic cavity as shown in black dots and on the virtual surface as shown in blue dots for the configuration (a) d5cm_w15cm; (b) d10cm_w15cm.

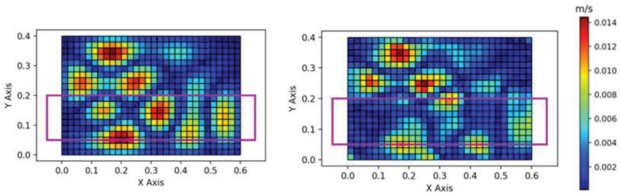


(a) (b)

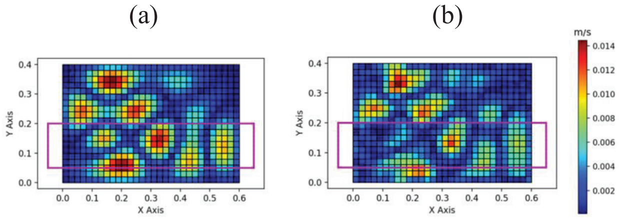
Figure 3. The 2D YZ view of the spatial distribution of sensors in the virtual acoustic cavity as shown in black dots and on the virtual surface as shown in blue dots for the configuration (a) d10cm_w15cm; (b) d10cm_ w30cm

3.2 Identification Step

The velocity field is identified using Equation (3) and the previously detailed data. It is important to note that the surface of identification corresponds to the surface of the plate, thus from the principle of continuity, the particle velocity is equal to the structural velocity of the plate. The computed plate and identified velocity fields are compared in terms of the norm velocity as presented in Figure 4 and 5. These results demonstrate the iPTF process can provide satisfactory results for this kind of identification with partial masking of the source by an obstacle.

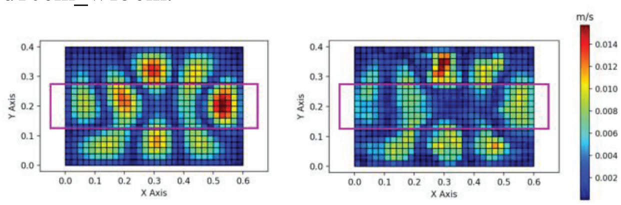


(a) (b)

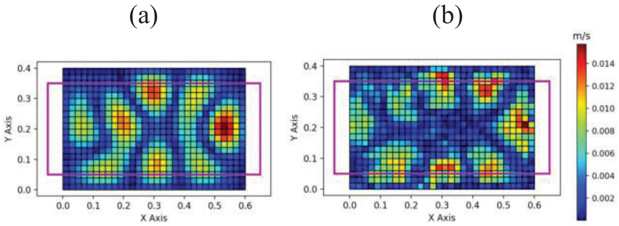


(c) (d)

Figure 4. The norm of the velocity field for the first configuration at 500Hz (a) computed on plate (reference) for d5cm_w15cm; (b) identified by iPTF for d5cm_w15cm; (c) computed on plate (reference) for d10cm_w15cm; (d) identified by iPTF for d10cm_w15cm.



(a) (b)



(c) (d)

Figure 5. The norm of the velocity field for the second configuration at 400Hz (a) computed on plate (reference) for d10cm_w15cm; (b) identified by iPTF for d10cm_w15cm; (c) computed on plate (reference) for d10cm_w30cm; (d) identified by iPTF for d10cm_w30cm.

4. CONCLUSIONS

In this article, iPTF has been used to identify velocity fields in the presence of obstacle. The main advantage of the method is the combined use of the integral formulation, FEM and measurements, which allows to overcome inherent limitations of classical methods. This paper gave an overview of the theoretical background and the numerical measurement methodology. To prove the method efficiency, a numerical validation was set up with a simple supported plate partially masked by a rigid obstacle. This identification has been compared to plate structural velocity. The results show a good comparison, which confirms the expected advantages, and demonstrate the applicability of the iPTF method.

5. ACKNOWLEDGEMENTS

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