Application of Virtual Acoustics to Automotive Sound Quality

B. J. Feng & G. H. Wakefield
Ford Motor Company, Dearborn, MI, 48121
University of Michigan, Ann Arbor, MI, 48109

1. INTRODUCTION

Traditionally, automotive sound quality engineering is based on empirical acoustic measurements, and therefore requires the availability of physical prototypes. This poses a number of problems with respect to the continuing desire to reduce product development costs and shorten development schedules. Physical prototypes that are suitable for assessing the sound quality performance of a vehicle design are generally expensive to produce due to the accuracy required, and because they are fabricated largely without the benefit of production tooling. Furthermore, the high cost of such prototypes restricts the numbers that are available to the engineer, leading to development delays. Also, limited access to test facilities suitable for sound quality work can also pose a bottle neck for empirically based engineering. Finally, because "sound quality" prototypes are often not available until well into a design cycle, sound quality motivated design changes can have significant ramifications on production and tooling costs.

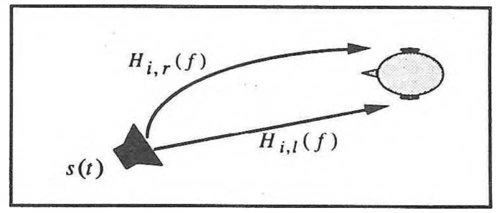
Virtual prototyping addresses these problems by making available, to the engineer, noise performance data for a vehicle or component design before it is possible to build and empirically test a physical prototype. Virtual prototyping depends on several enabling capabilities. The first is the capability to analytically predict the vibro-acoustic response of a structure design based solely on an engineering description (i.e. the virtual vehicle) and a target driving excitation. [1] The second enabler, virtual acoustics, provides the capability to predict the left/right ear signal (e.g. the binaural signal) for a virtual listener that is immersed in the predicted acoustic field of a virtual vehicle.

DESCRIPTION

When a customer forms an impression of the sound quality of a particular vehicle, it is primarily based on the sound as received through both the left and right ears, e.g. binaurally. The chief reason why the binaural format is important is that it preserves directional hearing information. When one listens to binaural sound data, the location and size of acoustical objects are preserved. In contrast, single point or monaural sound data completely lacks this directional information. Furthermore, the timbre of a sound source can also depend on direction. In point of fact, many established methods for quantifying automotive sound quality are based on analyses of binaural sound data.

Given a prediction of the acoustic radiation over the interior surface of a vehicle, it would seem a simple matter to determine the net acoustic signal at a point equivalent to a hypothetical driver's ear. It could be done by simply summing contributions from various acoustic sources, considering attenuation due to distance from each source. However, this strategy will not produce an acoustic prediction that accurately reflects the subjective characteristics of the sound field as it is perceived by the customer because it lacks the directional hearing characteristics of the human auditory system as mentioned above. For the same reason, a pair of spaced omnidirectional microphones is also a poor approximation of the human hearing process.

Virtual acoustics is the technology of predicting/synthesizing binaural sound data for a given listener at a given location in a 3-dimensional sound field. Virtual acoustics is based on having a detailed characterization of directional dependent hearing response for both the left and right ear. This characterization is usually realized as a set of paired (left & right), complex transfer functions, also known as head related transfer functions (HRTF). For a source located at a particular azimuth and elevation angle, there exists a unique pair of HRTF's from the source to each of a hypothetical listeners ears. The signal entering each of the ears can therefore be predicted by using the HRTF pair as a set of directional filters to modify the source signal, as shown in the figure below.



Here s(t) represents the predicted acoustic radiation for some part of a vehicle's body structure. The functions, $H_{i,l}(f)$,and , $H_{i,r}(f)$, are the left and right ear directional transfer functions (e.g. HRTFs). The signal entering the left ear of the virtual listener is therefore computed as:

$$x_{i,l}(t) = h_{i,l}(t) * s_i(t) \qquad \textbf{(EQ 1)}$$

where $h_{i,r}(t)$ is the time domain impulse response for the left ear transfer function. Given a set of HRTF's distributed across azimuths and elevations surrounding ones head, one can compute the directional dependent left ear signal for multiple sound sources as,

$$x_l(t) = \sum_i h_{i,l}(t) * s_i(t) \qquad \textbf{(EQ 2)}$$

and similarly for the right ear signal. The resulting left/right ear signals will be a subjective and objectively good prediction of what a real person would experience if a real prototype were available.

CONCLUSIONS

Virtual prototyping will be a powerful tool for helping automakers cut costs and reduce vehicle development time. Virtual acoustics is the part of virtual prototyping that allows an engineer or customer to experience the virtual noise environment of a virtual vehicle, and is thus make possible the application of automotive sound quality engineering without the need for costly physical hardware.

REFERENCES

[1] Deitz, D., "Breaking the virtual sound barrier," in Mechanical Engineering, June, 1996.