

Development of a New Squeak and Rattle Detection Algorithm

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ABSTRACT

A new algorithm to detect and to quantify the seriousness of the detected squeak and rattle (S&R) events was developed. A T-F analysis technique called AWT, the Zwicker loudness model and leaky integration are employed to define new concepts we called transient specific loudness time histories and perceived transient loudness time history. The detection threshold of the perceived transient loudness was identified by a clever interpretation of jury test results. The proposed algorithm showed a good promise producing results that are well correlated with the jury tests. The new algorithm developed in this work will be able to automate detection and rating of the S&R events with good accuracy and with minimum possibility of false alarm under normal operating conditions

INTRODUCTION

Squeaks and rattles (S&R) are highly detrimental to perceived NVH performance of the vehicle. Historically squeaks and rattles were detected and analyzed using subjective methods. In addition to inherent subjective nature, such an approach is very costly and time consuming. Despite numerous efforts to develop an automated method to detect and quantify S&R [1-4], there seems to be no widely accepted method to detect and quantify S&R in presence of background noise. The present study aims at developing a reliable method for automatic detection and quantification of the squeak and rattle events occurring in actual operating conditions.

S&R are unexpected noises of short time duration perceived by a listener to stand out from the background (expected) noise [3]. Squeaks are friction induced noise arising from stick slip motion of surfaces in contact. Its amplitude and frequency content depends on a host of complex factors such as material constituents, coefficient of friction, normal load and load history, sliding velocity, inertia and thermal effects, wear characteristics, temperature and humidity conditions, etc. Rattles are impact-induced phenomenon arising due to insufficient strength or loose connections [5]. Usually the energy of S&R event is distributed primarily in the frequency range 200Hz-15 kHz. The stick slip motions and impacts produce audible sounds when the adjacent surfaces are capable of effective radiation of sound energy. Usually, instrument panels, seats and doors are main culprits in S&R generation. References [4-8] give good review of mechanism of S&R events.

Sound files of various S&R events are available in digital form in reference [9] from which the sound files used in present study were obtained. 1/3rd octave band spectrums of a few common squeak and rattle events are given in Figure1. Significantly different spectral and temporal characteristics among different S&R events make it very difficult to develop a quantitative method to automate the detection of S&R events.

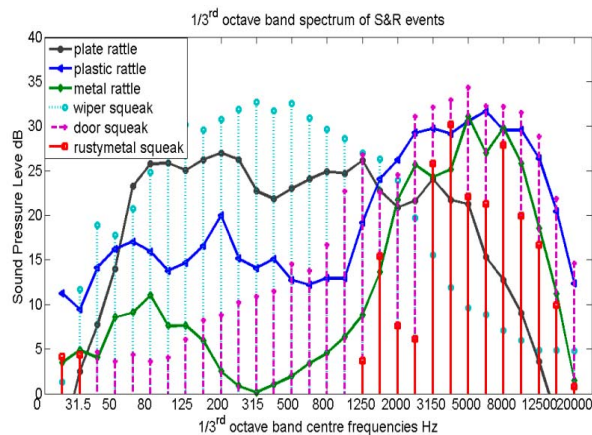


Figure 1 one third octave spectra of S&R events; generated using sound files from [9]

Basic physical quantities like sound pressure level (SPL) do not reflect the characteristics of human auditory system; therefore will not be useful in predicting perceived S&R performance. Conventional subjective metrics like stationary loudness values will not be sufficient because squeaks and rattles are transient events with low signal to noise ratio (SNR) occurring in presence of background noise. Even the clearly audible S&R events under normal operating conditions can have very low SNR. These events become audible due to the remarkable spectral and temporal resolution of human auditory system that works like a bank of overlapping filters operating simultaneously on sound signals. S&R events will become discernable when its energy level in at least one of these filters is higher than that of the background noise. Bandwidth of the auditory filter can be approximated as critical bandwidth.

Spectral masking is another important aspect of human auditory system that affects the perceived level of S&R event. Masking occurs when the perception of one sound is affected by the presence of another sound [10]. This arises due to the overlapping nature of auditory filter banks. Use of percentile characteristics of loudness values estimated from filtered sound signal was suggested as metric for evaluation of S&R events by Brines et al. and Feng et al [1, 11]. However, removal of low frequency background noise will also result in removal of masking produced due to filtered components. This will lead to false detections, detecting S&R events which are not actually audible.

In order to overcome these challenges, a new S&R detection algorithm is proposed in this work. An in-stationary loudness model based on Zwicker transient loudness (DIN 45631/A1) [12-16] with the temporal integration scheme proposed by Glasberg and Moore [17] is adopted. The proposed algorithm employs new techniques or concepts such as use of analytic wavelet transform (AWT) to obtain the time-frequency (T-F) characteristics of the S&R event, transient loudness to

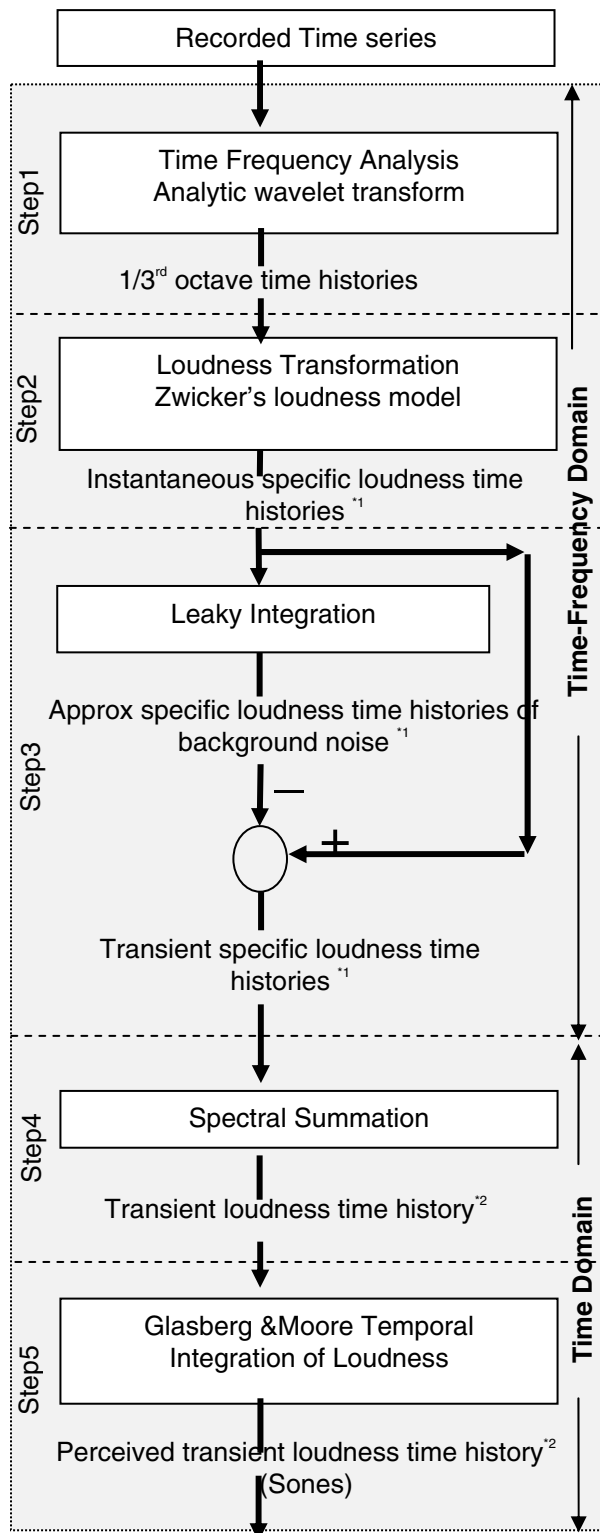
separate the background noise, and the general detection threshold to enable more reliable detection of S&R events.

DEVELOPMENT OF A NEW ALGORITHM FOR SQUEAK AND RATTLE DETECTION

The new S&R detection algorithm we developed utilizes the perceived transient loudness (PTL) time history. S&R events are detected when the value of the perceived transient loudness value exceeds the S&R detection threshold. The perceived transient loudness time history and the S&R detection threshold are new concepts developed in this work which can be obtained as explained in the following.

THE PERCEIVED TRANSIENT LOUDNESS (PTL) TIME HISTORY - Figure 2 shows the block diagram representation to calculate the perceived transient loudness (PTL) of the given recorded sound signal. The PTL time history can be understood as the loudness of the transient events perceived by human separated from the background noise. The results from jury tests are used to develop detection threshold for S&R events. The occurrence of S&R is detected by comparing the PTL time history of the given noise with corresponding detection threshold.

Step1: T-F Analysis - Because S&R events are highly time-localized, conventional Fourier analysis is not suitable to characterize the events [1, 15, 18]. T-F analysis should be applied to the recorded time history of the noise to capture instantaneous characteristics of the noise.



*1 : set of time histories at 1-24 barks *2 : A single time history

Figure 2 Block diagram of detection algorithm

Short time Fourier transforms (STFT) and wavelet transform are the two widely used T-F analysis techniques. Previous studies [1, 15, 18] have clearly demonstrated the inherent weakness of Fourier transform based techniques in T-F analysis of squeak

and rattle events. In the present study the analytic wavelet transform (AWT) technique developed by Zhu and Kim is used [19, 20]. The AWT they developed is a special version that performs like a virtual real-time 1/3rd octave filters. The noise is characterized as a set of 1/3 octave time histories in this step.

Step 2: Loudness Transformation - The transformation of sound signal from physical domain to sensory perception takes place in this step. The 1/3rd octave band histories obtained in the previous step are converted to loudness time histories in critical bands 1 to 24 using the Zwicker's loudness model [12-15]. The model accounts for the transmission characteristics of outer and middle ear and spectral processing characteristics of human auditory system. The instantaneous specific loudness in auditory filters corresponding to critical bands 1 to 24 are obtained as a set of 24 time series in this step.

Step 3: Calculation of transient loudness Time Histories - Human recognizes S&R events when the auditory sensation produced by these events causes noticeable changes above the masking effect of background noise. Therefore, the contribution of transient events to auditory sensation can be obtained by removing the background noise, which can be done in an approximate sense. For this purpose, the instantaneous specific loudness time histories obtained in the previous step is averaged by the leaky integration. The output of the leaky integrator approximates the specific loudness time histories corresponding to the background noise. The leaky integration of the specific loudness time histories is conducted as

$$N'_s(i) = (1 - \alpha_t)N'_s(i-1) + \alpha_t N_s(i) \quad (1)$$

Where, N_s is the instantaneous specific loudness and N'_s become the approximate specific loudness time history of the background noise and α_t the time constant of the integrator. An integrator with a time constant of 0.05 sec was found to be optimum. This implementation captures the slow varying changes in specific loudness pattern due to speeding or slowing of the automobile, while the sudden changes in specific loudness arising due to S&R events are minimized. The output of the leaky integration is a set of time histories of the masking noise in critical bands.

As it is shown in Figure 2, the transient specific loudness time histories are obtained by subtracting this slow varying masking noise time histories from the specific loudness time histories obtained in step 2. This transient specific loudness time histories approximate the loudness of the transient events above the background noise in each critical band.