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Synth Challenge 2025: Report

Introduction

The goal of Synth Challenge 2025 was to synthesize the sound of an electric motor. In addition to the raw control signal data, a description of the provided data and a video recording from inside the simulator was provided.

Techniques

Preprocessing

Upon initial inspection of the control data, it was noted that the sampling frequency was 250 Hz. This is *much* lower than the 44.1 – 48 KHz usually used in recording audio and meant that, if the audio was generated with the same sampling frequency as the data, the resulting sound would have a Nyquist frequency of 125 Hz. Therefore, the data was upsampled to 48 KHz using the MATLAB `resample` function to avoid any issues with aliasing.

Engine Noise

A research paper titled “Effect of Pole and Slot Combination on Noise and Vibration in Permanent Magnet Synchronous Motor” [1] was used for the purposes of recreating the sound of an electric motor. Unless otherwise noted, all information in this section is taken from this source.

The primary source of vibrations in a permanent magnet synchronous motor (PMSM) is “unbalanced radial force [that] will lead to great vibration on the stator” (page 1). The specific frequencies of these modes are directly related to the number of slots in the stator N_s , which result in harmonic orders of $f = iN_s, i \in \mathbb{N}$. Additionally, the number of magnetic poles N_p also directly affect the frequencies of the vibrations, with harmonic orders of $f = (2k \pm 1)N_p/2, k \in \mathbb{W}$. For the purposes of this project, an 8-pole/12-slot PMSM was chosen to simplify the attenuation of each harmonic order, as a graph in the paper itself showed the amplitudes of the harmonics up to order 24.

To implement this model, each harmonic was created using a phase accumulator [6]. To approximate the attenuation of each harmonic order as shown in Figure 5 [1], the first harmonic order was multiplied by a factor of 0.5, and each subsequent order was multiplied by a factor of

$e^{-(n-2)}$, with n representing the index of each subsequent non-zero harmonic order in the sorted array of all non-zero harmonics.

Tire Noise

The car in the simulation video went over a few sections of uneven road, which in a real-world situation would be heard in the automobile cabin as dull thuds. While audio synthesis of these sounds was initially attempted by using subtractive synthesis with different colors of noise (similar to synthesis of drum sounds), it was ultimately decided to use granular synthesis to manipulate an already pre-recorded public domain sound [2]. Since the source sound was longer than desired (around 0.4 seconds in duration), the original sound was sliced up into 10.67 ms (512 sample) frames and windowed with a Hamming window. These were then rearranged and reconstructed using the overlap-add algorithm (OLA) to shorten the sound to just 0.2 seconds.

The timestamps of the individual bumps were then identified by squaring the derivative of the vertical acceleration of the entire car, applying thresholding to eliminate peaks due to noise, and then identifying the indices of the remaining peaks. It should be noted that, a priori, it would be better to identify bumps in the road by calculating the vertical acceleration of each wheel from its provided position vector. However, it does not appear that the columns labeled “Wheel Pos Y” actually track the vertical position of the wheels, but instead likely tracks their locations along one of the axes in the horizontal plane (labeled in the description of the control signals as the XZ-plane). Once the indices of the peaks were identified, a single sound vector was constructed by using OLA to add the shortened impact sound at the location of each peak.

Wind Noise

Finally, it was decided to add some wind noise to the final sound to improve realism. This is because all cars are susceptible to some amount of wind noise due to failures/imperfections in components such as weatherstripping. During literature review, a study was found that measured the power spectrum of underwater ambient noise due to wind [3]. While not exactly a one-to-one comparison (viz. the study was on acoustic waves in water as opposed to air), it seemed to indicate a noise spectrum very similar to red or pink noise.

As such, wind noise was implemented in this project via subtractive synthesis. Namely, white noise was filtered to create pink noise [4] and, since the wind noise level is dependent on the speed of the vehicle, shaped with an envelope that had an amplitude based on the ratio of the instantaneous RPM relative to the max RPM.

Reverberation

Because the driver of an electric vehicle is seated inside a closed cabin, any sound generated will naturally reverberate within the very small space. As such, code for a Schroeder reverberator provided by Prof. Čmejla during the Week #10 lab session of the SYN course was adapted to simulate such reverberations [5].

References

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2. https://commons.wikimedia.org/wiki/File:Dull_thud.ogg
3. Murugan, S. Sakthivel, Natarajan, V., Kumar, R. Rajesh, Noise Model Analysis and Estimation of Effect due to Wind Driven Ambient Noise in Shallow Water, International Journal of Oceanography, 2011, 950838, 4 pages, 2011.
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