Synthetic engine noise generation for improving electric vehicle safety

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Abstract: Electric cars are commonly known not only to be environmentally friendly, but also to be very quiet. While a quiet car is generally a good thing, safety concerns have been raised that Electric Vehicles (EVs) may cause more frequent accidents involving pedestrians than Internal Combustion Engine (ICE) cars, as pedestrians may not notice an approaching EV. This paper conducts noise level measurement for EVs and ICE cars at different speeds. We then describe the implementation of a synthetic engine noise generator and examine its performance and its acceptance among drivers and pedestrians.

Keywords: battery-electric vehicles; REV; renewable energy vehicle; engine noise; sound generation; EV safety.

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1 Introduction

Electric vehicles run very silently at low speeds, and in many cases, pedestrians only a metre away are not aware of a moving vehicle and do not realise the potential danger. This poses a potential safety risk for EVs, especially in car parks and parking structures. Pedestrians have been trained to the sound of cars for making themselves aware of traffic. When a car cannot be heard, pedestrians may incorrectly assume they are safe. Two major groups of pedestrians are more at risk than others. These are children and vision-impaired people. Blind and vision-impaired pedestrians have to rely on audible traffic clues. The potential danger of electric cars for them has been highlighted in a number of published reports and news pepars (NHTSA, 2010; Magda, 2006; Muffett, 2010; Nuckols, 2007; Whoriskey, 2009). The higher traffic risk for children and infants with conventional ICE cars has been frequently examined, e.g., in drive-way reversing situations (Paine, et al., 2002). According to an Australian study (Williamson et al., 2002) "*more than a third of pedestrians aged under six killed in motor vehicle crashes are struck down 'off road' in yards, car parks and driveways*" and motor car driveway accidents are the number two killer of Australian children under five years of age at home (Australian Family, 2011). Silent electric cars could even aggravate this problem. A Swedish study for slow moving vehicles including agricultural vehicles found in a five-year study that slow-moving traffic is only responsible for about 1.3% of all traffic injuries in Sweden (Pinzke and Lundqvist, 2004). Although this seems to be a small percentage, the arrival of quiet electric cars may significantly increase this problem in the future.

A secondary issue is the missing audible feedback for the driver of an EV, especially since a number of trial car conversions, such as the cars seen in Figure 1 of UWA's Renewable Energy Vehicle Project (Bräunl, 2011), do require manual gear shifting without a clutch. The absence of an engine sound makes it very hard to shift gears, as the driver has to wait for the motor speed to drop or accelerate to the right value to be able to select the next gear down or up.

Figure 1 Electric vehicles REV Eco (Hyundai Getz) and REV Racer (Lotus Elise)

2 Existing engine sound generators

A number of automotive sound generators are available either as after-market systems, most prominently for sound-tuning of ICE cars, or as standard equipment from EV manufacturers.

- Vroombox offers an inexpensive after-market sound generator (Vroombox, 2011). This system is targeted at ICE cars, using the car's tachometer output as well as a supplied vacuum sensor as inputs, but could be modified to suit EV needs.
- Lotus Group has developed an aftermarket sound-generator system called Halosonic, targeted specifically at EVs (Lotus, 2010; Patrascu, 2009). Halsonic is based on realistic engine sounds, but can be set to artificial sounds as well. This is a side product of Lotus' cooperation with Tesla Motors, providing the EV manufacturer with car shells for the Tesla Roadster.
- A number of electric vehicle manufacturers, including General Motors, Nissan, Toyota and Mitsubishi have developed integrated artificial sound systems for their upcoming EVs, e.g., the standard engine sound equipment for the Mitsubishi iMiEV EV (Hanada and Yoshida, 2007). None of these sound generators are trying to reproduce realistic engine sounds. Instead, they are using non-automotive related warning sounds or even the horn in case of the GM Volt.

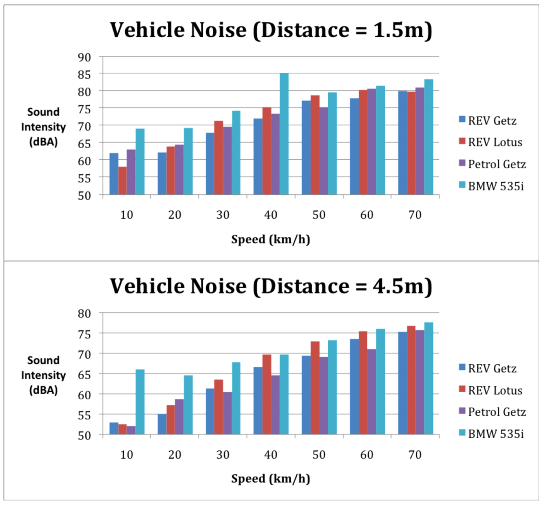
- The motor controller Curtis 1231C does emit a clearly audible high pitch noise when driving at low speed. Although this could quite effectively be marketed as a deliberate safety feature of the motor controller, however, (Hart, 2011) points out that this is merely due to the fact that the manufacturer had to use a reduced clock speed (1.5 kHz instead of 15 kHz) for the lower 15% throttle positions, to have sufficient time during a control cycle when operating at the current limit (especially during starting phase). This controller is used in the REV Eco Getz (Bräunl, 2011).

3 Sound level measurements

Before advocating an artificial engine sound device for electric cars, it is important to establish whether or not there is a need for such a system. It appears to be almost common knowledge these days that '*electric cars are silent*', but we first have to do comparative measurements to answer the question '*How silent are EVs really?*' and under what circumstances, such as distance and speed.

As summarised in Figure 2, we have conducted comparative sound level measurements between the petrol and the electric version of a Hyundai Getz (REV Eco), as well as our electric converted Lotus Elise (REV Racer) and a petrol-driven BMW 535i. The tests have been conducted at a range of different speeds and at two different distances.

Figure 2 Sound level measurements



Concentrating just on the direct comparison between the electric REV Eco Getz and the standard petrol Getz, it can be clearly seen from the collected sound data that the electric Getz is about 3 dbA quieter than its petrol counterpart at short distances. At a 4.5 m distance, the EV is about equal in noise level at 10 km/h and quieter at 20 km/h, but gets even louder than the petrol-driven car at speeds of 30 km/h and above.

As for the other two cars in the sound measurement test, the electric REV Racer Lotus Elise is even less silent than the electric REV Eco Getz at 10 km/h. This is due to the fact that the electric Getz requires two hydraulic pumps for power steering and brake assist, while the electric Lotus does not require these auxiliary devices (not even in the petrol-driven version). The BMW 535i is significantly louder than all other cars at all speeds and at both distances, however, the discrepancy is highest at low speeds, while the sound level of the BMW is very similar to the other cars at higher speeds (e.g., 60 km/h and above).

When stationary, electric cars do not idle, and therefore, do not emit any noise at all. Thus, their stationary measurements match the slightly fluctuating ambient noise around 50 dBA, while the petrol-driven Getz registered 56.0 dBA while idling at a close distance (1.5 m). A major difference between electric and petrol cars occurs, however, when accelerating from stationary. In this potentially hazardous scenario for pedestrians, EVs are still silent (ambient noise only), while petrol cars emit significantly higher noise levels than when cruising at a constant speed. We measured 64.5 dBA for an accelerating petrol-driven Getz (almost identical for near and far measurements), which matches the sound level of the same car driving at a constant speed of 40 km/h.

The result that EVs are only silent at low speeds was expected, as wind noise and tyre noise will contribute the lion's share to vehicle noise at higher speeds for any car, irrespective of whether the drive system is electric or internal combustion.

Although we have only conducted measurements for two EVs and two ICE cars, we believe that these measurements demonstrate a general trend and can be generalised for other EVs as well, whether they are conversions or purpose designed EVs. Our findings clearly narrow down the usefulness of any EV engine sound system to slow driving speeds, e.g., below 25 km/h. Especially during starting (stationary) phases, EVs are completely silent. Thus, even a device that only signals starting and reversing of an EV to pedestrians would have a significant benefit.

4 Engine sound system

4.1 Sound sampling

The first step was sampling the original engine sound, which we did with the REV Lotus before its petrol engine was replaced, and with a number of other cars, including a Ferrari f350 and an Aston Martin DB9. The final engine sound synthesis system is independent of the sound samples, so the driver can select the sound samples to be used to generate the engine sound he or she prefers.

A high-quality directional condenser microphone was used for sound recording. It was placed about 50 cm behind the car exhaust. Audio was then recorded with an audio software suite onto a PC. Engine RPM were held constant for about three seconds during recording and this procedure was conducted at regular RPM readings, from 1,500 to 9,000 RPM.

4.2 Vehicle sensor input and sound output

There are various options for sensor input from the vehicle to control the generated engine sound, e.g., electric engine RPM sensor (tachometer output), gear position, vehicle speed from speedometer or GPS, accelerator pedal position, etc. For the REV Racer Lotus, we used an even simpler method, utilising a drive system current sensor, which roughly corresponds to engine revs, in addition to the car's GPS speed.

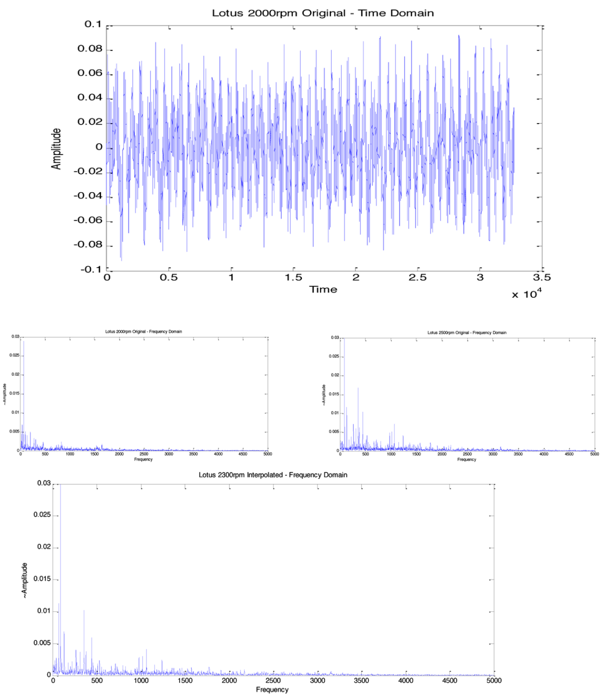
This allowed us to implement the engine sound system with minimal interference with the vehicle. Although our goal is to run the vehicle sound system on a dedicated embedded hardware, we have implemented the prototype for the Lotus on our existing in-car automotive PC (core 2-duo), which also serves a number of other tasks, including driver information, data logging and telemetry. Sounds are being played back through an amplifier and vehicle mounted waterproof marine speakers.

4.3 Audio processing

Audio processing is required to increase the resolution between recorded audio samples and to blend between them (Morey, 2010). Our audio processing algorithms are described in detail in (Hellsten, 2009). We were able to decrease the RPM increment between samples by producing interpolated samples to fill the gaps. Audio samples at 50 RPM increments are sufficient to produce a smooth engine sound. While several methods for this interpolation were available, we have explored wave synthesis, Fourier interpolation, and frequency shifting. As wave synthesis turned out to be too compute-intense for the planned embedded hardware implementation, we will only describe Fourier interpolation and frequency shifting in this section.

The Fourier interpolation method takes advantage of the full range of recorded samples while maintaining a smooth transition between interpolated samples. In the frequency domain, data sets are created as linear interpolations between two recorded samples, producing the Fourier transform of a wave, blending the two recorded samples (see Figure 3).

Figure 3 Original sound sample with Fourier transformations and interpolation from



Source: Hellsten (2009)

Unfortunately, engine sounds generated through Fourier interpolation do not sound realistic. The dominant frequency of the first sample fades away while the dominant frequency of the second sample strengthens. An audible pulsing noise is created through a beat effect of the two similar dominant frequencies.

In the end, the simpler method of frequency shifting for interpolating audio samples was chosen for this engine sound project. Every audio sample was edited to have a fade-in of 0.05 s from zero to maximum volume. Similarly, a fade-out is required, to avoid a popping noise when blending between samples. However, since it is not possible to know when such a change of samples will be dynamically required, the fade-out must be controlled by software in real-time rather than by editing the audio sample.

To add more depth to the engine sound, three samples are used at all times instead of one (Hellsten, 2009). An idling sample is used to represent the low engine rumbling noise. A sample at 3,000 RPM represents the medium-pitched engine noise and a sample at 7,000 RPM (depending on the sampled car engine) represents the high-pitched engine noise. The set of three samples is used to produce a full spectrum using the frequency shift method in the RPM range 1,500 RPM to 9,000 RPM.

The final sample of an RPM value is now blended from the three individual samples, using different volume coefficients. This reflects the difference in dominance of each component in the final sample, depending on the RPM value. For example, for generating the frequency blend at the low frequency of 1,500 RPM, the low rumble component gets 100% volume while the other two components are switched off. At 2,000 RPM, the rumble components decreases to around 70% volume, while the medium components increases to 30% and the high pitch component still remains switched off. The process is maintained for higher RPMs.

We have synthesised an engine sound from a collection of audio samples, which blend smoothly in and out. The samples can increase or decrease in pitch while still preserving the engine's typical audio profile and both ends of the RPM spectrum. There are no audible fade-in or fade-out transitions when switching samples and overall, the synthesised engine noise sounds realistic, and is aesthetically pleasing.

5 Practice tests

We have conducted numerous practice tests with our REV Racer Lotus, with and without generated engine sound.

5.1 Driving without engine sound generation

When starting or reversing from stationary, the car cannot be heard and pedestrians or bicyclists will not notice it or go out of its way, which can be a safety hazard. The same problem exists at slow speeds, e.g., in a parking lot. Pedestrians do not notice the approa–ching car and will not make way for it. The Lotus has neither power brakes nor power steering, so it does not even have a small noise level from hydraulic pumps, as other typical EV conversions do have.

On several occasions, the horn had to been used to signal the oncoming car or to ask pedestrians to move off the road; however, this is not a very courteous thing to do and a less drastic method of alerting other road users would have been preferred.

5.2 Driving with engine sound generation

Playing back generated engine sounds does work for pedestrians, bicyclists, and generally any other traffic and, therefore, the hazard of a silently approaching car is averted. The approaching car is recognised and precautions are taken, although the generated engine sounds do still differ significantly from the original petrol Lotus sound (or any ICE car), mainly due to the limitations of the amplifier and speakers used.

For the driver, the generated sound does give some audible feedback for the engine revs, which is useful for assisting in manual gear shifting as well as generally desirable for a sports car. The actual playback volume of the generated engine sound can be adapted to the vehicle speed, but using an inverse linear relationship, i.e., the generated sound gets quieter at higher speeds (in contrast to an ICE car), as the noise generated through wind resistance and tire roll have taken over the safety function by then. If so desired for purposes of driver feedback at higher speeds, the engine sound could be played back solely in the cabin.

6 Summary

We have given a motivation for engine sound systems based on vehicle accident statistics and presented an overview of existing engine sound systems for EVs. Our measurements have shown that engine sound systems are only required at very low vehicle speeds (up to around 25 km/h) and more importantly, for starting and reversing an EV. The belief that electric vehicles are silent at any speed is only a myth. We have further demonstrated a practical implementation and audio processing system for generating engine sounds from exchangeable sound sample files and presented results from its practical trial.

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