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Virtual Engine Sound Synthesis of Eco-Friendly Vehicle

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Abstract: According to the development of vehicle science and technology, motors that move using the forces generated by the internal combustion engine have been moved by electric motors. Although, the number of electric-only vehicles is still lower than that of oil-filled vehicles, electric vehicles are expected to be widely used for various reasons in the future. In particular, various low-pollution vehicles have been manufactured and operated according to the demand to develop environment-friendly vehicles worldwide. These eco-friendly cars have advantages in common and low noise in our shop. Particularly when running at a low speed, a slight operation sound is generated and it is difficult to notify the inside and outside of the vehicle that the vehicle is moving to the people. Vehicles using an internal combustion engine burn fuel and air according to four or two strokes inside the engine whether low speed or high speed. At this time, the energy generated by consuming the fuel moves the vehicle. In addition, various pollutants that we do not want are generated. Examples are exhaust gas, noise, vibration and heat. Among them, noise can be used as a means of notifying the people around the vehicle of the warning or danger of a moving vehicle if the noise is as specified in the standard. In this study, we will discuss the method of releasing engine sound during the operation of environment friendly vehicles. In order to reproduce the engine sound, we analyze the existing engine sounds and propose a method of making the engine sound using the sound generation and synthesis principle. Devices such as the existing VESS simply record the engine sound of the vehicle and reproduce it according to the situation. However, the proposed system uses less memory but can reproduce coterminous engine sounds.

Key words: Virtual engine, eco-friendly vehicles, combustion sound, internal combustion engine, engine sound synthesis, VESS simply record

INTRODUCTION

After the industrial revolution in the 18th century, people are doing a lot of researcher using fossil fuels. In particular, it has become possible to utilize the force of the internal combustion engine in moving means to move quickly, far, comfortably and conveniently. And with the development of various technologies, the power source that relies on the internal combustion engine is gradually moving into electricity. Although, the number of eco-friendly vehicles are still lower than that of oil-filled vehicles, electric vehicles are expected to be widely used for various reasons in the future. In particular, various low-pollution vehicles have been manufactured and operated according to the demand to develop environment-friendly vehicles worldwide. Vehicles using an internal combustion engine burn fuel and air according to 4 or 2 strokes inside the engine whether low speed or high speed. At this time, the generated energy for moving the vehicle and additionally, heat and sound are generated, also. If this noise is around the standard, it will be noisy but it can be used as a means to inform the people around the vehicle of the warning or danger of the moving vehicle. However, eco-friendly cars have advantages in common and low oil consumption and less exhaust emission and low noise. Particularly, at a low-speed driving, a small operation noise is generated and it is difficult to inform the inside and outside of the vehicle that the vehicle is moving (Dongki *et al*., 2013; Bum-Moon and Young-Dae, 2015) .

Eco-friendly cars include electric-automobiles, hydrogen-cars and hybrid-cars. The basic feature of this eco-friendly automobile is that less environmental pollutants are emitted by exhaust gases. Other advantages include low fuel consumption and low noise. However, low noise, one of the advantages of eco-friendly automobiles is a drawback for the following reasons. When the driver drives the vehicle at low speed, the moving noise of the vehicle does not occur and the pedestrian of the vehicle is not informed that the vehicle

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s approaching. That is, low noise is an advantage to prevent noise pollution but it is a fatal disadvantage and leads to a car accident. VESS (Virtual Engine Sound System) was developed to prevent accidents caused by such low noise vehicles. VESS is a system that recognizes the fact that the vehicle is approaching the pedestrians by regenerating the artificial engine sound made by the moving sound of the vehicle to prevent accidents caused by the noise and the advantages of the environment friendly vehicle. However, VESS is installed in the vicinity of the engine of the vehicle to reproduce the sound is played. This method lacks research on the acoustic characteristics of the loudspeaker and the transmission characteristics of the sound heard by the pedestrian, so that the sound is not efficiently transmitted to the pedestrians. And, although it was developed, it is not obligatory to install it in an environmentally friendly vehicle by law, so, it is not actually used any more (Dongki *et al*., 2013; Bum-Moon and Young-Dae, 2015).

Generally, the process of making sound is done by combining the excitation source with the resonance parameter which is the propagation process. However, sounds that use electronic devices such as VESS have been developed focusing on storing and playing original sounds. The same is true in the process of creating virtual engine sounds with ordinary environmentally friendly vehicles. It mainly reproduces the engine sound of gasoline vehicles or certain preferred vehicles and informs the surrounding people and the driver by supplementing quiet sound. However, this method is not efficient to use a large amount of memory and it is disadvantageous to generate various engine sounds at once. In this study, we introduce the study of synthesis of sound according to the sound generation principle to make virtual engine sound.

MATERIALS AND METHODS

Basic theory of sound engineering and engine sound: The sound is generally caused by a variety of causes. In the case of a musical instrument, kinetic energy or potential energy such as friction, collision, repulsion, air flow, etc. between the object and the object is converted into sound energy to shake the surrounding air molecules together. And the sound heard by a person is expressed by the resonance of the cause and the transmission process when creating a virtual engine sound, the excitation source and the resonance parameter can be analyzed. This process can be expressed as a block diagram as shown in Fig. 1. And as shown in Eq. 1, it is

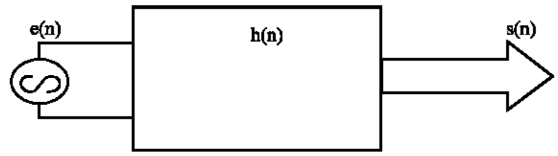

Fig. 1: Block diagram of sound synthesis model

possible to make a synthesized engine sound by convolution sum in the time domain or multiplying the frequency domain. Where e(n) represents the input excitation source, h(n) represents the system transfer parameter and s(n) represents the sound heard into the air (Rabiner and Schafer, 2011; Park and Bae, 2017; Bae and Lee, 1998; Jee *et al*., 2016a-c). Through this process, we can synthesize different virtual engine sounds according to the desired speed, RPM and vehicle type. In the case of the conventional VESS, sound is recorded and mastered according to various characteristics and sound is reproduced according to each speed, RPM and vehicle engine type. In order to do this, an expensive sound system and a memory for storing sound are additionally required (Jee *et al*., 2016a-c). And in order to reproduce the sound, a speaker is installed inside the engine room to produce sound. In this way, it is possible to produce a sound of a common internal combustion engine. However, due to the nature of sound transmission, the loudspeaker inside the engine room is low in radiation efficiency into the air and the resonance structure changes during the transmission, making it difficult to make the virtual engine sound that was intended (Jee *et al*., 2016a-c):

$$\begin{aligned} s(n) &= e(n)\times h(n) \\ S(\omega) &= E(\omega)H(\omega) \end{aligned} \tag{1}$$

Today, automotive engines are divided into three categories: gasoline engines, LP gas engines and diesel engines. As shown in each name, it is classified according to the fuel used mainly. However, the gasoline engine and the LP gas engine are similar in structure and form, so they are used in a similar form. The difference between the two engines is that they differ in the way they mix the fuel with the oxygen and in the equipment required depending on the location. Of the three engines, diesel engines differ in the way they burn from the other two engines, so, the sound produced by the engine is also very different. There are a lot of parts that constitute a general automobile engine but the part where the main power is carried is divided into three parts by crankcase, cylinder block and cylinder head. The crankcase has a crankshaft that changes the reciprocating motion of the piston into rotational motion and the cylinder block is actually the skeleton of the engine in which the piston moves. Finally, the cylinder head has an intake valve and an exhaust valve that open and close according to the movement of the piston. In the case of a gasoline engine there is an ignition plug. In the case of a diesel engine there is a fuel injection nozzle. In the case of a gasoline engine, the fuel and oxygen are compressed inside the engine cylinder and exploded using a spark plug. In the case of a diesel engine, the more air is compressed to a higher pressure than a gasoline engine to generate heat which causes combustion of the fuel. So, the diesel engine moves the cylinder a long distance and produces high pressure exhaust gas. These characteristics make diesel engines more vibration and noise (Jee *et al*., 2016a-c).

Here are what causes the engine to sound to synthesize the engine sound. Depending on whether the engine type is four or two, the cause of the engine sound is basically the explosion process occurring inside the cylinder. In the case of a four-stroke engine, four explosions are made during two rotations of the crankshaft in four stages: intake-compression-explosion-exhaust. In the case of a two-stroke engine, an explosion takes place during one rotation of the crankshaft in two processes: intake, compression-explosion and exhaust. The high-temperature, high-pressure exhaust gas from this explosion pushes the cylinder to create a force that drives the engine and moves the vehicle. And additional emissions, heat, sound and vibration that we do not want are also generated. And those that exit the engine cylinder filter the pollutants through the exhaust pipe and reduce the size of the noise with the Helmholtz resonator. That is, the explosion sound corresponding to the impulse becomes the excitation source of the engine sound and the system transfer function becomes the characteristic of the resonance exhaust pipe. And the engine operates and the sound of the cooling fan, the generator and the engine itself which is generated further, vibrate the air through the resonance of the engine room and the body and it is heard in our ears (Jee *et al*., 2016a-c).

RESULTS AND DISCUSSION

Virtual engine sound through sound synthesis: In order to create a virtual engine sound through synthesis, we proceeded through the following process. The process is the same as the block diagram in Fig. 2. Existing enginesounds were measured and collected by fuel and by characteristics. In the next step, the recorded sound source was analyzed and the feature parameters were extracted by dividing the RPM and various situations. In the next step, the analyzed sound source is divided into parameters that can be used for synthesis through the optimization process. In the next step, the characteristics were identified in engine category, RPM, time domain and frequency domain and psychoacoustic parameters of sound were extracted and optimized. In the next step, the engine sound is generated by synthesizing the excitation source of the engine sound and the engine characteristic sound parameter and then transmitted to the stage for reproduction. In the reproduction step, the sound generated by the synthesis is reproduced and the sound quality is adjusted in consideration of psychoacoustic parameters and the like.

The engine sound according to the conventional engine type was collected and analyzed. Gasoline engine and diesel engine were recorded and analyzed. The characteristics of the gasoline engine sound are summarized briefly, the fundamental vibration and sound occurs at about 35 Hz, the loud and light sound of the harmonic structure occurs and on average, it occurs 6 dB quietly than the diesel engine. The characteristics of the diesel engine sound are summarized briefly, the fundamental vibration and sound occurs at about 35 Hz and it is about 6 dB larger than the gasoline engine and several harmonic structures are generated. The result of this analysis is the octave band analysis of graphs in Fig. 3.

We want to synthesize the engine sound based on the above analyzed values. The parameters needed to synthesize the engine sound are as follows. As a result of analysis based on fundamental resonance frequency

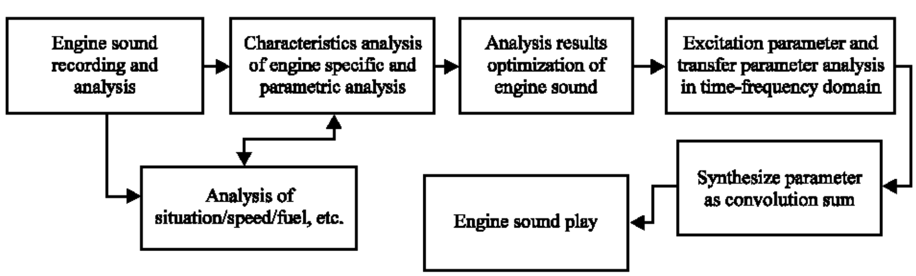

Fig. 2: Synthesized virtual engine sound block diagram

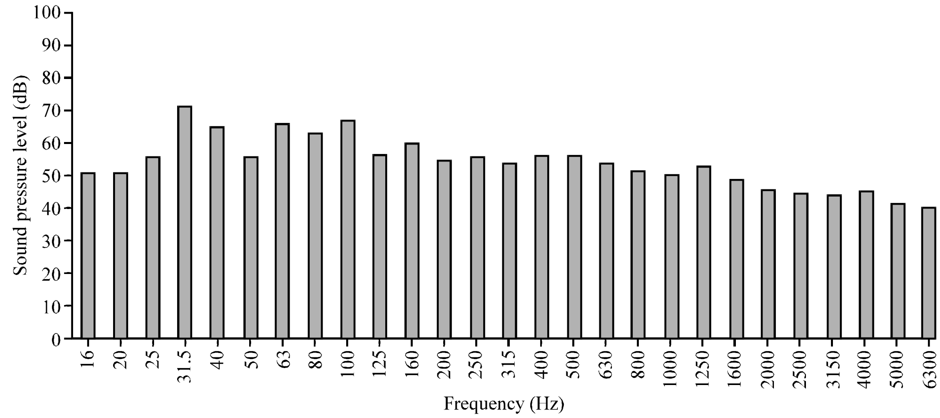

Fig. 3: Gasoline engine sound 1/3 Octave band analysis

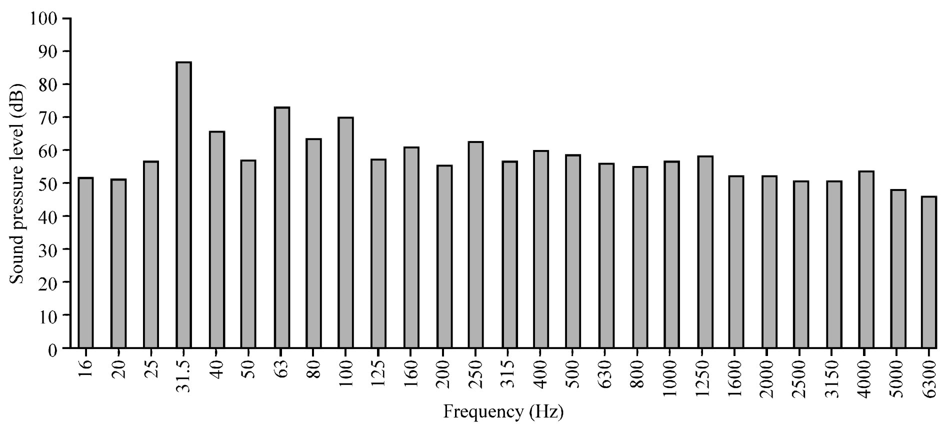

Fig. 4: Virtual gasoline engine sound 1/3 Octave band analysis

and harmonic structure, no change in system parameters was observed. Furthermore, the main sound changes are the parameters of the height of the source and the height of the harmonic according to the change of the position of the fundamental resonance frequency. Thus, the convolution sum of the time domain of the excitation parameter and the transfer function parameter in the frequency domain proposed in study was performed to generate one section of reproduction sound. Since, the change of the sound source can be recognized for about 0.2 sec by utilizing the human auditory characteristic, the sound source is synthesized in 0.2 sec units and the sound source is overlapped by 30%, so that, the connection is made smoothly. The synthesized engine sound is shown in Fig. 4. Although, the magnitude of the absolute value of the reproduced sound source is different, it can be confirmed that the portion of the system parameter and the result shape excited by the fundamental resonance frequency are similar.

CONCLUSION

A variety of vehicles have been developed and used due to the development of scientific civilization of mankind. Especially today, environment-friendly cars are expected to lead the automobile market in the future in the context of high oil prices and the depletion of oil and coal. Eco-friendly vehicles have the advantage of less emission of environmental pollutants, less noise when moving and less fuel consumption. However, the disadvantage is that there is a risk of a car accident because the engine sound is very fine at low speeds. In this study, we propose a method to synthesize a variety of high quality engine sounds by analyzing the existing engine sound, modifying it with the cause of the cause and changing the engine sound changing system parameters and storing the data. As a result of synthesis of the engine sound, it was confirmed that the engine sound can be regenerated almost like the conventional engine sound. In addition, it is confirmed that various kinds of engine sounds can be generated according to taste and characteristics by using the synthesis method.

RECOMMENDATIONS

In the future, we will simplify the algorithms to reduce the time required to synthesize these engine sounds and optimize the sound sources used in synthesis. In addition, we will also study the method that can reproduce the sound directly from the surface of the vehicle in the method using the vibration speaker.

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