Development of Electric Vehicle (EV) Warning System to Alert Pedestrian Using Fuzzy Logic

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Abstract: - Silence is a condition where people always prefer. Unfortunately, not everything that comes in silence is good for human being. Electric vehicle (EV) is one of the technologies that build for quiet road vehicle as it moves smoothly using electric motor instead of a rough and raw gasoline engine. The quiet characteristic posed by EV especially when the car moves at a slow manoeuvring speed such as entering a parking lot or junction and reversing will bring danger to the people around it. Due to the lack of engine noise in EV, other road users are exposed to prominent threats by the car. For common gasoline type vehicle, engine noise will act as a sound cue to notify people especially when the car moves at low velocity but that is not the case for the silent EV. Several main car manufacturers are already aware of the issue and develop a warning system to alert other road users. This paper discussed warning systems that have been developed to alert pedestrian on oncoming EV. The system will utilise fuzzy logic concept to optimize the output warning sound. The system validation discussed the sound and fuzzy behaviour.

Key-Words: - Electric Vehicle, Warning Sound, Alert Pedestrian, Fuzzy Logic

1 Introduction

Green technology started to get popular nowadays. Electric vehicle (EV) is one of the green technologies prominently developed in automotive industries. Most of the EV are used as a town cars in United State (US) and some European countries. EV is a vehicle which used electric motor powered by electricity stored in a high performance battery instead of a gasoline engine using gasoline. The use of electric motor in EV to drive the vehicle can save the environment since zero-tail pipe emission will be produced. Unfortunately because of this, the vehicle moves quietly which cause difficulties for the other road users to detect the presence of the car especially when it moves at low speed, such as entering a junction or parking space and reversing [1]. National Highway Traffic Safety Administration (NHTSA) in the US is the one of those who received complaints from pedestrian regarding the issue. They consider this problem seriously because based on the accident statistical data, 77 pedestrian and 48 bicyclists were involved in crash with EV and hybrid EV from year 2000 to 2007. Alfred Zeitler, an engineer at BMW stated in his recent research that when an EV reaches a speed of 30-35km/h, the car becomes noticeable because of the noise generated from the tire and aerodynamic-wind friction [2]. This noise is sufficient for the pedestrian to detect the car.

This issue has been taken seriously by EV manufactures after it had been highlighted by NHTSA in 2009. Nissan Motor Corporation had developed and already introduced a system in their latest EV; Nissan Leaf called Vehicle Sound for Pedestrian (VSP) [3]. The VSP system only activates at certain speeds as shown in Figure 1. It will turn-off when the vehicle is in idle condition and at the speed of 30km/h and above. Besides that General Motors also introduce warning sound to their EV; Chevrolet Volt called Pedestrian-friendly Alert System. Lotus Engineering also introduced warning sound system to their concept plug-in hybrid car, Lotus Evora 414E Hybrid called HALOsonic Internal and External Electronic Sound Synthesis.
Every new technology cannot run from critics. National Federation of the Blind (NFB) in U.S reported that most of the alert sound coming from the newly developed system for EV to alert them is still confusing and not effective especially to the blind person [4]. This happens because the sound character which is intermittent and it is hard for them to classify the exact situation. They also stated that the sound only increases the noise level of the environment and will irritate people with annoyance [5]. Sound annoyance can cause frustration and affect personal daily routine. In-term of physiological reactions, a person who is constantly exposed to sound annoyance can lead to hypertension, increasing heart rate and blood pressure [6].

The sound selection to be used on the EV is a vital part during the development of the system. The sound needs to be specially developed to consider every element involved, such as annoyance, detect-ability and recognisability. In this research, the proposed signal to be employed in the control system is an engine sound from the normal vehicle. This is because the engine noise produced similar impact when alerting pedestrian on the road. Figure 2 shows the vehicle perceived distance for pedestrian to detect the oncoming car. Several different background sound pressure level was chosen to test the pedestrian detectability. As proven by NHTSA, at low speed EV is hardly detected by the pedestrian as compared to the internal combustion engine (ICE). The detect-ability of pedestrian to EV becomes similar to the ICE when the speed is increasing [7]. Engine noise is one of the suitable sounds to be used as an alert signal in the development of the control system. Most of the developmental systems introduced by EV manufacturers are based only on the speed of the car [3]. In this research, new approach for the system was tested to optimize the noise level for detection and at the same time protect the environment sound level. The fuzzy logic concept was used in the system to make it operate intelligently.

2 Control System Design Concepts
The proposed system optimizes the output, which is the engine sound by using fuzzy logic concept to control the system. For this research, Arduino UNO ATmega328 Microcontroller Processor is used to control the input and output of the system. The controller processed inputs from two sensors to get the system output. Hall Effect sensor is used to detect and calculate the vehicle speed whilst an ultrasonic sensor is used to detect pedestrian distance. The two inputs are processed using a fuzzy logic controller embedded in the microcontroller to optimize the output. The output of the system, which is engine sound, was initiated by attaching a speaker and the signal is amplified to produce better sound for detection. The sound was uploaded in the SD Card Module and after that the fuzzy output is finalized; the signal is automatically executed according to desired outputs. Figure 3 shows briefly the control system flow.
2.1 Fuzzy Logic Controller (FLC)
Fuzzy logic technology applied engineering experience and experimental result to achieve the desired output for the system. The microcontroller acting as FLC after the fuzzy program had been uploaded to execute the system. Fuzzy system consists of three main processes that must be passed before the output is produced which is shown in the Figure 4. The processes are Fuzzification, Inference and De-fuzzification.

Fuzzification process involves conversion of the measured quantity into a number of fuzzy that represent the values which is called fuzzy set. In the control system two measured inputs were involved using two sensors that are connected to Arduino UNO ATmega328. Hall Effect sensor will measure and calculate the speed of the vehicle whilst the ultrasonic sensor will calculate the distance of the detected pedestrian. The fuzzy set of the inputs was represented in the membership function graph to determine the level of the input. The first input is distance detection level which is measured by the ultrasonic sensor. The membership function graph is made up by combining the trapezoidal and triangular shapes. Figure 5 shows the graph for pedestrian distance detection. The detection distance was divided into three levels which are hazard, average and safe. Hazard level means that the pedestrian is too close to the vehicle and the possibility for crash to happen is high. The detection level is followed by average and safe.

To make sure that the engine sound is activated only when the vehicle speed is below 35km/h [2], the Hall Effect sensor was used. The sensor detects the tire revolution per minute (RPM) and convert it to vehicle speed. The speed will then be fuzzify and converted to a fuzzy set number. The number is represented in the membership function graph as shown in Figure 6. Similarly, the speed level is also classified in three levels; In-Range, Intermediate and Out-Range. The control system is activated only in the In-Range level, whereas intermediate level is for safety factor purposes. The system is completely off when it is in the Out-Range speed.

The output of the fuzzy logic control, which is the engine sound also need to be classified into a membership function graph. Figure 7 shows the graph for level of engine sound that act as
an output for the control system. The level of the sound is divided into six categories. The first three of the noise; warning, alert and safety is when the vehicle speed is in range level. The last three of the sound which is safety 2, safety 3 and safety 4 is executed when the car velocity is in the intermediate range.

Rule 6: If Pedestrian Distance SAFE and Vehicle Speed INTERMEDIATE, Then Engine Noise is SAFETY 4
Rule 7: If Vehicle Speed OUT-RANGE, Then Engine Noise TURN-OFF

2.2 Engine Signal Characteristics
In the FLC, six levels of engine noise are used as an output of the control system. The signals are divided into two categories. The first group of sound are Warning, Alert and Safety. These sounds are activated based on the pedestrian detection and also when the vehicle speed is between 0 to 35km/h. The second sound group comprises of Safety 2, Safety 3 and Safety 4. These sounds are triggered when the vehicle speed is within intermediate level.

Intermediate level is required as safety factor purposes before the FLC control system is completely de-activated at the speed of 50km/h and above. Since the transition of speed in the Intermediate level is short and acts as a safety factor, the sound that will be used is broadband frequency noise or white noise. The noise is chosen because of the less annoyance and good detect-ability characters of the sound [8]. The usage of the engine and white noise is to differentiate the noise transition at Intermediate speed level.

3 Control System Validation Test Setup
Once the control system had been set accordingly, two tests were conducted to validate the system based on the output performance, which is engine noise and fuzzy output value behaviour. The test setup follows the standard from the International Standards Organization (ISO) and the Society of Automotive Engineers (SAE) for the measurement of minimum noise emitted by road vehicles.
The sound was tested in two positions, Front Centreline (FC) and Front Parallel (FP). The FC and FP are location for the microphones which are placed 1.2m from the ground. The FC and FP points are chosen because they can describe as a situation when the vehicle started to move and try to pass by the pedestrian. Figure 8 shows the dimension and position of the FC and FP point.

3.1 Control System Test Procedure

For the test procedure, the engine sound levels were measured at both FP and FC positions at different vehicle speed. For the purpose of this research, since the system is just a prototype, it will detect the speed of the rotating fan. The rotation on the fan is considered as the same as the rotation of the tire vehicle. The rotation of the tire is converted to vehicle speed based on equation (1).

\[ V \text{ (km/h)} = \left( \frac{\text{Rotating Tire wheel rpm} \times \left( \frac{92.6 \text{ (mm)} \times 2\pi \text{ (rad)}}{2 \times 12 \text{ (in) \times 1000}} \right)}{60} \right) \times 60 \]  

(1)

As shown in Figure 8, for measurement at point FC, the microphone was located at the front of the system with 2 metres distance between each other. The engine sound level was measured at different rpm of the vehicle especially when the vehicle starts to move. The measurements were taken from minimum of four readings from the microphone at the speed between 0 to 600rpm. Adequate sound level should be produced if the system detects pedestrian when the vehicle start to move to alert them. For measurement at point FP, readings are taken at different speed based on the tire rotation speed. The tire rotation can be converted into speed based on equation (1). The value of the sound will then be added to the tyre noise that has already been collected based on previous research.

The results were compared with the previous research done on ICE vehicle in alerting people especially at neighbourhood area [9].

4 Results

The engine signal sound level of the system is measured to validate its level of appropriateness to be used as a pedestrian alert system for EV. The first measurement is at point FC, front centre of the vehicle. The position of the sound source is vital for the pedestrian as the vehicle starts to move from an idle situation or parking lot. Table 1 shows the value of the measured sound level.

<table>
<thead>
<tr>
<th>Tyre Test RPM</th>
<th>Vehicle Speed (Km/h)</th>
<th>Sound Level (dB)</th>
<th>Fuzzy Output Value</th>
<th>Engine Noise Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>7.2</td>
<td>66.0</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>200</td>
<td>14.4</td>
<td>66.3</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>300</td>
<td>21.5</td>
<td>66.9</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>400</td>
<td>28.7</td>
<td>67.4</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>500</td>
<td>35.9</td>
<td>69.7</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>600</td>
<td>43.1</td>
<td>71.0</td>
<td>55.9</td>
<td>Safety 2</td>
</tr>
</tbody>
</table>

Table 1, Result of Measurement at FC point

Figure 9 shows the sound measured at the centreline 2 metres in front of the control system. The sound level was measured as a function of the tire rotations per minute. In the figure, the sound pressure level (SPL) at lower speed, which is 100rpm or 7.2km/h recorded reading is 66.0 dB. The readings keep increasing proportional to velocity and at the speed of 43.1 km/h the value is recorded at 71 dB.

For the second measurement, point FP, front parallel was chosen. As the vehicle moves forward at low-speed, the signals must be adequate to be detected by pedestrians. Table 2 shows the measured value at point FP.
Table 2, Result of Measurement at FP point

<table>
<thead>
<tr>
<th>Vehicle Speed (Km/h)</th>
<th>Tyre Noise (dB)</th>
<th>Total Noise (Sound Level + Tyre Noise)</th>
<th>Fuzzy Output Value</th>
<th>Engine Noise Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.0</td>
<td>58.7</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>10</td>
<td>47.0</td>
<td>66.0</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>15</td>
<td>58.0</td>
<td>67.8</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>20</td>
<td>64.0</td>
<td>68.5</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>25</td>
<td>67.0</td>
<td>69.0</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>30</td>
<td>67.5</td>
<td>70.2</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>35</td>
<td>71.5</td>
<td>73.4</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>40</td>
<td>73.0</td>
<td>74.5</td>
<td>12.4</td>
<td>Warning</td>
</tr>
<tr>
<td>45</td>
<td>73.8</td>
<td>75.3</td>
<td>100.0</td>
<td>Safety 2</td>
</tr>
</tbody>
</table>

*Refer to Reference [9] for tyre noise

For FP position measurement, the sound level will be added to the tyre noise in order to obtain the total noise of the system since in this situation the vehicle is in motion. Moving vehicle is producing noise but after 30-35km/h, the total noise produced is sufficient for the pedestrian to detect the incoming vehicle [2]. Figure 10 shows the sound level values at different speed measured from FP position. In the beginning, the tyre noise SPL is much lower than total noise emitted by the system. The total noise value is almost the same value with tyre noise at the speed above 35km/h.

5 Discussions

From the measurement values of the control system, the data are compared with results from previous research that had been conducted by ECTunes. Previous research focused on the minimum noise emitted by road vehicle at point FC and FP.

The first measurement of SPL is at point FP. Previous conducted experiment uses two different ICE vehicles, which was a new Mitsubishi Colt 2010 Clear tech 1.3 and an eight years old Skoda Fabia Combi 1.4 Classic. The result of the measurement is shown in Figure 11. During the test, the data is measured based on different engine rpm. In the experiment, instead of using various engine rpm, the data is being measured based on tyre rpm from Hall Effect Sensor.
The main focus of undertaken measurement in FP position is to measure the value of engine SPL from the control system that is adequate for pedestrian to detect the vehicle when start to move at the slowest speed. From the experimental result, at speed 7.2km/h the SPL value was 66.0dB. In Figure 11, the reading of SPL at lowest speed is around 54dB for Mitsubishi Colt and 61dB for Skoda Fabia. The control system sound is a little bit higher than the two ICE vehicles. The reason is there will be no starter sound for the control system, to maintain the quiet EV compared to the ICE car. The starter noise reading for both ICE cars is around 70dB and 72dB. The starter noise is unnecessary for the quiet EV. The control system eliminated starter sound to optimize the sound emitted by the control system.

![Fig. 12, Noise measurement at FP Point](image)

Figure 12 shows the vehicle pass by noise. The value is measured at the point FP, when the microphone is parallel to the car front. In this figure the tyre noise was added with the engine noise SPL for total noise emitted by the car. The experiment was also conducted by ECTunes. In Figure 11, the engine noise covered by the total vehicle noise at low speed but after 20km/h the engine noise drop and tyre noise over-shadow the total noise. For the control system, data shown in the Figure 10 is almost the same pattern as Figure 12. The tyre noise becomes the same as total vehicle noise when it started to speed-up at 35km/h. The engine sound in the control system is sufficient to alert the pedestrian similar to ICE noise. The engine sound automatically turn-off after 50km/h as the noise from tyre is sufficient for pedestrian detection. The values for the total SPL of the signal for both experiments are different even though the input is almost the same. It is due to different microphone position (FP and FC). Also, at FP position, tyre noise value was added to the sound level for total vehicle noise emitted, as shown in Figure 10.

6 Conclusions
As for the conclusion, the implementation of the fuzzy logic in the control system can optimize the output of the system, which is engine sound. The sound is only activated when needed based on the speed and condition of the EV. The control system delivered the sound based on the situation (pedestrian distance level) at low velocity and de-activated after the speed reached 50km/h. Before it turned-off, the intermediate speed range level is acting as safety factor action that used broadband frequency or white noise as an alerting signal. This is because white noise is easily detectable by a pedestrian.

Engine noise used in the system, has been tested and compared with ICE vehicles for sound sufficiency as alert signal. At FC position, the EV does not produce any noise during start-up. After the car started to move and the system detects the pedestrian, engine noise will be emitted to warn them. The SPL at lowest speed is adequate to warn pedestrian on incoming EV, especially at speed 0 to 10km/h. At FP point, where the vehicle will pass-by the pedestrian, based on the speed and distance, the system produces slightly high SPL at the beginning compared to ICE vehicles. After it reaches 35 to 45km/h, the value is almost the same as a normal car.

The control system with a fuzzy logic controller can optimize the engine sound and produce compatible total vehicle noise for environmental protection.

Acknowledgement
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References:
[1] National Highway Traffic Safety Administration (NHTSA), Incidence of Pedestrian and Bicyclist Crashed by


[7] Ulf S., Luc G., Piotr M., 2010, Are vehicle driven in electric mode so quiet that they need acoustic warning signals?, 20th International Congress on Acoustic, ICA, PACS: 43.50Lj, 43.66.Qp
