Sudden noise source localization system for intelligent automobile application with acoustic sensors

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***Abstract*—This paper suggests an automotive application for finding direction of sudden noise source in driving situation. The system applies sound source localization algorithm using microphone array sensor and finds the direction of the abrupt abnormal noise sources. Representative experimental results demonstrate its feasibility as new safety car electronic component.**

I. INTRODUCTION

On the road, many sudden noises like car horns, crashes or sirens bombard drivers and demand their attention. However, it is often tiring and dangerous to check source of all these distractions with the rear view mirror or by turning one's head. In these situations a Heads Up Display (HUD) notifying the driver of the noise location would be very helpful. Drivers will be able to assess their vehicle's position relative to others without taking their eyes off the road. Moreover, this system can be very helpful to the hearing-impaired.

This paper proposes a real time sudden noise source localization system utilizing acoustic sensors, supplementing the laser sensors, infrared sensors and CCD sensors that appear in other driver assistance systems.

We use a 3-channel microphone array for minimum computational overhead and evaluate its spatial resolution for multiple source localization.

II. PROPOSED SYSTEM

The proposed system block diagram is outlined in Figure 1. If the sudden noise occurs, the multichannel microphone array captures the acoustic sound. The array geometry introduces a small delay between microphones called the Time Delay Of Arrival (TDOA). Using the multiple inputs, we estimate the TDOA with the Steered Response Power – PHAse Transform (SRP-PHAT) algorithm. Using these delays and the microphone array geometry, we calculate the direction of arrival (the source localization process is described in Section III). Finally, the result is displayed on the HUD for the driver as depicted in Figure 2.

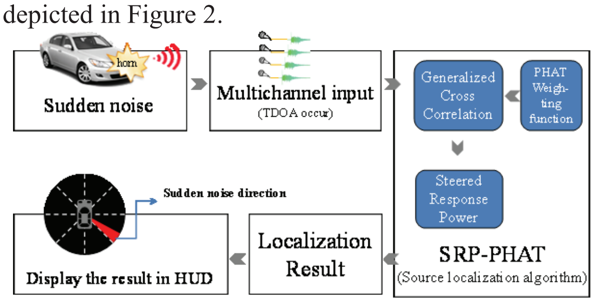

Figure 1. Block diagram of the Sudden Noise Source Localization system.

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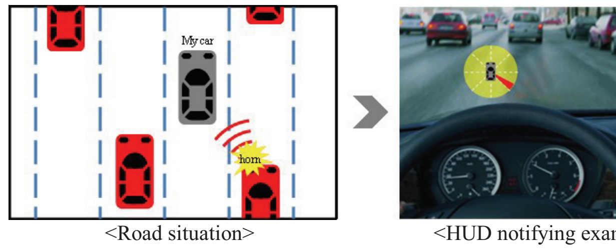

Figure 2. A depiction of the system's sound source result displayed on HUD.

III. MULTIPLE SOUND SOURCE LOCALIZATION

There are many source localization algorithms in literature; such as MUSIC[1], SRP-PHAT[2-3], Phase Difference[4], etc., to name a few. Among these, SRP-PHAT is known to be the most robust to noise and is computationally efficient, so we opt for this algorithm to evaluate the microphone array performance.

A. Microphone Location

The microphones would ideally be set up outside of the car. However, when the car is moving, wind greatly reduces the signal-to-noise ratio so setting the microphones inside of the car is unavoidable as shown in Figure 3.

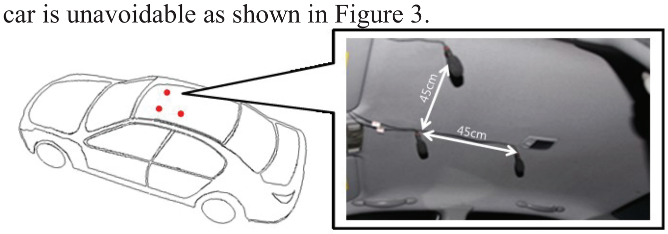

Figure 3. Microphone array setup inside of car

B. SRP-PHAT

We assume a far-field model where the curvature of the propagating sound waves is considered negligible.

A brief description of SRP-PHAT algorithm is as follows. The General Cross Correlation (GCC) of the l-th and q-th microphone signals is:

$$R_{lq}(\tau,n)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\Psi_{lq}(\omega,n)X_l(\omega,n)X_q'(\omega,n)e^{j\omega\tau}d\omega \quad (1)$$

where n is the frame index, $X_l(\omega,n)$ is the Short-Time Fourier Transform(STFT) of l-th microphone, ω is the frequency index, and $\Psi_{lq}(\omega,n)$ denotes a weight function. Although many different weighting functions can be applied, the Phase Transform (PHAT) has been found to perform quite well under realistic acoustical conditions [5]. The PHAT weight function is defined as:

$$\Psi_{lq}(\omega,n)\equiv\frac{1}{|X_l(\omega,n)X_q'(\omega,n)|} . \quad (2)$$

Using GCC-PHAT of the l-th and the q-th microphone signals, we can estimate the TDOA as:

$$\hat{\tau}_{lq} = \arg\max_{\tau}(R_{lq}(\tau)) \cdot \quad (3)$$

The SRP-PHAT algorithm is equivalent to summing GCCs. Thus, the SRP-PHAT algorithm output can be expressed as:

$$P_n(\Delta_1\Delta_2\ldots\Delta_M) = \sum_{l=1}^{M}\sum_{q=l+1}^{M}\int_{-\infty}^{\infty}\Psi_{lq}(\omega)X_l(\omega,n)X_q(\omega,n)e^{j\omega(\Delta_q-\Delta_l)}d\omega \quad (4)$$

where Δ_m is the propagation delay from source to the m^{th} microphone. Δ_1 Δ_2...Δ_m are equivalent to candidate source locations. It is guaranteed that the global maximum of the SRP corresponds to the location of a sound source.

We propose a modified SRP-PHAT algorithm for full azimuth multiple source localization [6] as follows:

$$\hat{P}_n(\theta) = 2\pi \cdot \min_{1\le l,q\le M}\left(R_{lq}(\tau_{lq,\theta}, n)\right) \quad (5)$$

where $\tau_{lq,\theta s}$ is the TDOA between the l^{th} and the q^{th} microphones of a sound source at relative angle θ_s.

We can localize the direction by finding the maximum angle from Equation (5) by:

$$\theta_s = \arg\max_{-\pi\le\theta\le\pi}(\hat{P}_n(\theta)) \cdot \quad (6)$$

IV. Experiments

A. Experimental conditions

Before real world testing, it is necessary to explore the localization system angular resolution of 3-channel array. We attempted to mirror the experiment conditions with a car interior as much as possible as shown in Figure 4. The microphone interval was 45cm and the Signal-to-Noise-Ratio (SNR) was set to 5dB, a high threshold considering indoor ambient noise is 45dB on average and sound source is 50dB. We used a recorded horn sound as the sound source and played it with speakers.

We used two loudspeakers with one fixed at 81° and the other one moved closer from 85°. Then, we recorded several times for accuracy and repeatability.

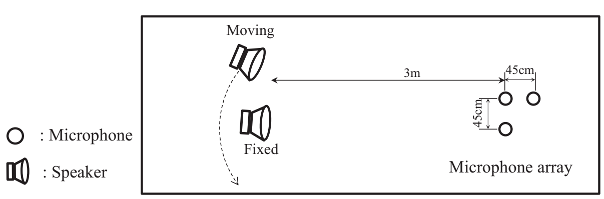

Fig. 4. Multichannel microphone array and indoor condition

B. Experimental result

The minimum distinguishable angle where the steered response power(SRP) does not merge into one peak is 4° as shown in Figure 5. A 4° precision provides sufficient resolution for distinguishing several noise sources simultaneously on the road.

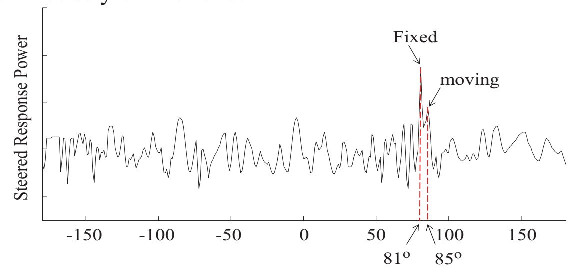

Figure 5. SRP corresponding angle in indoor experiment

C. Feasibility test of localizing sudden noise in real car

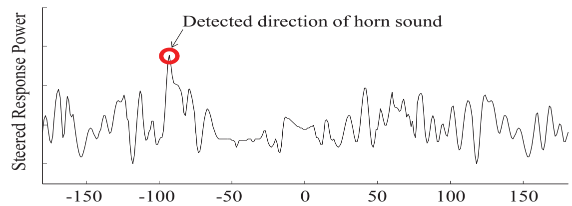

Figure 6. SRP corresponding angle in feasibility test

To verify the system for feasibility, we set up the microphone array in the real car as shown in Figure 3. We then conducted a listening test on the road. Horn sounds were activated many times using another car behind the car set up with sound source localization apparatus. Unlike indoor conditions, there were a lot of sharp noises and some not steep. However, the sudden noise was loud enough to localize exactly as shown in Figure 6.

V. Conclusion

Using the SRP-PHAT algorithm, we evaluated the performance of multiple source localization in a real world environment. By gathering additional acoustic information, the driver can make more informed decisions and practice safe driving. Not only the HUD, but also other user interfaces can be combined with this system to enhance the driving experience.

References

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