DIAGONAL MICROPHONE PLACEMENT FOR THE LANDSCAPE/PORTRAIT INTERCHANGEABLE MODE OF A PERSONAL COMPUTER

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ABSTRACT

This paper proposes diagonal microphone placement for the landscape/portrait interchangeable mode of a personal computer. Two microphones are diagonally located at a screen corner to provide useful directivity for target-signal enhancement in both landscape and portrait modes. The diagonal microphone placement guarantees a nonzero microphone spacing in either the landscape and the portrait mode along the ground surface leading to successful interference attenuation. Evaluations in a speech recognition scenario demonstrate that the diagonal microphone placement is effective in both the landscape and the portrait position with comparable command recognition rates of 80 to 99%.

Index Terms— Microphone placement, Diagonal, Array Processing, Signal enhancement Landscape, Portrait

1. INTRODUCTION

Lap-top PCs (personal computers) with a detachable screen and tablet PCs have been widely used for personal remote communication and teleconference. To enhance the target signal, which is mostly speech in such a scenario, acoustic beamforming or microphone arrays [1]-[7] with multiple microphones is known to be useful. From a viewpoint of cost-effective products, most lap-top PCs and tablet PCs are equipped with two microphones on the upper rim as depicted in Fig. 1 by gray circles e and f, which is the minimum number to form directivity. A typical placement of the microphones is the upper rim of the screen in the landscape mode. However, such a two-microphone placement does not work when the PC is interchangeably used in the landscape and the portrait mode. The microphones are aligned on a vertical line and do not provide microphone spacing along the ground surface.

As a solution to this problem, there is so-called L-shaped microphone placement [8, 9]. As depicted in Fig. 1, four microphones g, h, i, and j are mounted in a rectangular triangle shape at corner B of the rim [8]. When the PC is held in the landscape mode, microphones q and h on the horizontal rim are used. In the portrait mode, microphones i and j on the vertical rim, which is now held horizontal by the 90-degree tilt, are used. An even simpler placement with three microphones a, b, and c at corner A is disclosed by [9]. The microphone c is shared and combined with microphone ain the landscape mode and with microphone b in the portrait mode to reduce the number of microphones as well as analog-to-digital (AD) converters. This selective use of microphones guarantees horizontal microphone placement in whichever mode the PC is held. Two microphone signals always have time difference of arrival for signal sources in different directions on the ground surface and are useful for forming directivity. However, either of the L-shaped placement



Fig. 1. PC with standard and L-shaped microphone placement.

always requires at least one additional microphone and an AD converter compared to the standard two microphone placement, resulting in additional cost.

This paper proposes diagonal microphone placement for the landscape/portrait interchangeable mode of a PC. Although such a microphone placement looks straightforward, there is no literature about this placement nor its performance evaluation. The new microphone placement guarantees nonzero microphone spacing in either the landscape and the portrait mode, leading to good target-signal enhancement and interference attenuation for good output-signal quality.

2. HORIZONTAL MICROPHONE PLACEMENT

To form directivity along directions on the ground surface, conventional PCs have two microphones on the upper rim of the screen as the standard microphone placement. As illustrated in Fig. 2 (a), signals $S_0(t)$ and $S_1(t)$ arriving at the microphones e and f, in white and gray respectively, have a time difference τ of arrival for a plane wave coming from a direction ϕ . The time difference τ is given by

$$\tau = c \cdot d \cdot \sin \phi. \tag{1}$$

By measuring τ , the direction of arrival ϕ can be identified. It means that signals coming from different directions ϕ are assigned different gains to form directivity.

However, when it is tilted by 90° for the portrait mode, e and f are aligned on a vertical line as depicted in Fig. 2 (b). Signals $S_0(t)$



Fig. 2. Time difference of arrival between two microphones with standard placement (PC top view).



Fig. 3. PC with diagonal microphone placement. Set-in Portrait L mode is left- 90° tilted from Landscape mode.

and $S_1(t)$ arriving at the microphone e and f are identical and $\tau = 0$ for sources on the ground in any direction. No useful directivity can be formed in the portrait mode.

Solutions include another pair of microphones on a vertical rim of the screen [8] or a triangle microphone placement [9] at a corner like white circles a and b with a gray circle c. In either of these two cases, it is guaranteed that the microphone pair in use is placed horizontally to make $\tau \neq 0$.

3. DIAGONAL MICROPHONE PLACEMENT

3.1. Microphone Placement

Diagonal microphone placement at a screen corner necessitates only two microphones at *a* and *b* as depicted in Fig. 3. Although the upper right corner *A* is assumed here, one of other corners (B, C, orD)may be used instead. For a microphone spacing δ between positions *a* and *b*, the inter-microphone distance is $\delta \cos \theta$ and $\delta \sin \theta$ along the



Fig. 4. Directional noise suppressor with a constant beamwidth [12]. Beam steering is included because of an offset microphone position from the PC center.



Fig. 5. Directional gain $G_d(l, k)$.



Fig. 6. Beam steering for offset compensation of microphone positions from PC center.

horizontal and the vertical rim in the landscape and the portrait position, respectively. Because $\theta \neq 0^{\circ}$ nor 90° , the inter-microphone distance does not become zero in either position and useful directivity for interference attenuation can always be formed.

3.2. Beamforming

Traditional adaptive beamforming such as LCMV (linearly constrained minimum variance) beamformer, GSC (generalized sidelobe canceler) [1], as well as phase-based time-frequency (T-F) masking [10, 11, 12, 13] are all useful. When a sharp beam in the look direction is needed with two microphones, phase-based T-F masking is a better choice. Among others, a directional noise suppressor [12] is promising with a specified and constant beam width whose block diagram is depicted in Fig. 4. A directional gain database, which defines the repationship between the interchannel phase difference Δ of the two microphone signals and the gain as shown in Fig. 5, is equipped with. The microphone signals are summed in the frequency domain after discrete Fourier Transform (DFT) and applied a directional gain $G_d(l, k)$ in each frequency bin, where l and k are the frame and the frequency index.



Fig. 7. Experimental set-up (Top view).

When multiple channel signals are of interest such as multichannel communucation instead of speech recognition, a similar structure—citesugiyama20152 can be used instead of [12].

3.3. Beam steernig

For the diagonal microphone placement, beam steering is essential because of an offset microphone position from the PC center. Figure 6 shows an offset in the look direction of the diagonal microphone placement. Let us assume that the target signal comes from a direction perpendicular to the microphone array surface, *i.e.* $\phi = 0$. The target signal souce is located in the right front of the PC center. The look direction of the diagonally placed microphone pair for this signal source is Φ which makes an offset ϵ in the look direction from the standard microphone position as

$$\epsilon = \Phi - \phi. \tag{2}$$

In order to alleviate this offset ϵ , beam steering of ϵ is needed. In practice, the offset ϵ depends on the distance between the signal source and microphone array surface. Therefore, direction of arrival (DOA) of the target signal is estimated using the signals S_2 and S_3 at microphones a and b by a DOA estimation method [14].

Beam steering is also useful when the target signal does not come in the direction perpendicular to the array surface. In addition to the offset ϵ , the target DOA is estimated and combined to perform effective beam steering.

4. EVALUATION

Two microphones were fixed to the upper right outside corner of an iPad with $\theta = 45^{\circ}$ and the horizontal microphone spacing $\delta \cos \theta = 50$ mm. In this microphone placement, the vertical microphone spacing is also 50 mm. The microphone signals were processed by the directional noise suppressor with its diffuse signal gain set to unity. [7]. Passband beamwidths of 20° and 30° at signal-tonoise ratios (SNRs) of 6 and 0 dB were included in evaluation. A mouth simulator and a loudspeaker with alternating female and male speech of 200 commands were arranged as shown in Figs. 7 and 8. They were placed 305 mm above the center of the tablet PC.

Figure 9 compares directivities of the conventional (horizontal) microphone placement and the proposed diagonal microphone placement in the landscape mode. The attenuation for the target signal in black bullets was measured by changing the delay in one channel between -90° and 90° with the target signal in the look direction. A white square representing the interference was obtained by replacing the target with the interference when the look direction



Fig. 8. Actual experimental set-up in picture.



Fig. 9. Comparison of measured directivity (Landscape mode).

Table 1. Beam steering.		
	Landscape	Left-Tilt Portrait
Conventional	Left 5°	Left 20°
Diagonal	Right 15°	Left 18°

was set to ϵ_0 in the conventional microphone placement and Φ in the diagonal microphone placement. ϵ_0 is a look direction which provides the maximum output signal power. Note that beam steering of ϵ_0 for the conventional microphone placement and ϵ for the diagonal microphone placement was applied as in Tab. 1 which were obtained from the data in Figs. 9 and 10.

The upper and the lower figure depicts the directivity of the con-



Fig. 10. Comparison of measured directivity (Left-tilt mode, beam width = 20°).

ventional and the diagonal (proposed) microphone placement, respectively. In the look direction of $\epsilon = 0$, the conventional placement has 6.2 dB target-to-interference ratio (TIR). The diagonal placement in ϵ has 3.8 dB TIR. They can both separate the target and the interference with the corresponding TIR.

Figure 10 shows the same comparison when the PC is tilted toward left by 90° (L-Tilt mode). Microphones are closer to the inteference speech source than those without the tilt. Similar to Figure 9, the diagonal microphone placement provides a TIR of 7.3 dB while the conventional microphone placement achieves 0.52 dB. Clearly, beamforming with the conventional microphone placement is not successful. Thus, the diagonal microphone placement performs sufficient beamforming in both the landscape and L-Tilt modes while the conventional placement works only in the landscape mode.

Figure 11 compares the microphone signal (input) in black and the beamformer (BF) output in white. Enhancement is more significant in inactive sections of the target signal. Figures 12 and 13 show the command recognition rate with (Enhanced by BF in white) and without (No Processing in gray) beamforming in the Portrait L and the Portrait L mode. Portrait L refers to a Portrait mode obtained by tilting the tablet PC in the Landscape mode toward the left. SNRs were set to 6 and 0 dB, respectively. For SNR=6dB, in case of the conventional method, the beamforming does not help at all in the portrait mode as highlighted by dashed round square. On the contrary, the proposed micphone placement improves the ercognition rate by 10 to 19% in both the landscape and the portrait mode. This difference between the conventional and the proposed microphone placements becomes more significant at a lower SNR of 0dB.

5. CONCLUSION

Diagonal microphone placement for the landscape/portrait interchangeable mode of a personal computer has been proposed. Evaluations in speech recognition scenarios have demonstrated that the



Fig. 11. Microphone signal and output signal in Landscape and Portrait L mode.



Fig. 12. Command recognition rate for Portrait L (L-Tilt), Landscape, and Portrait R (R-Tilt) mode (SNR=6dB).



Fig. 13. Command recognition rate for Portrait L (L-Tilt), Landscape, and Portrait R (R-Tilt) mode (SNR=0dB).

diagonal microphone placement is effective in both the landscape and the portrait position with comparable correct command recognition rates of 80 to 99%. The diagonal microphone placement is applicable to laptop PCs with a detachable screen as well as tablet PCs, smartphones, and robots.

6. REFERENCES

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