2010 Symposium on Security Detection and Information Processing

Localization Estimation of Sound Source by Microphones Array

Jing Fan[*],   Qian Luo,   Ding Ma

School of Optoelectronics Information and Communication Engineering
Beijing Information Science and Technology University Beijing, China

Abstract

In this paper, we studied a localization estimation of sound source angle and distance by plane microphones array. We place the microphones on the peaks of equilateral triangle and square, estimate sound source angle and distance that from source to microphone according to different delays that from source to each microphones. We research an orientation segmentation method by analyzing the delay characteristics and a quick estimation algorithm to reduce the computational complexity. We introduce a quasi-L1-autocorrelation algorithm and an interpolation algorithm for improving estimation accuracy. The system can be used for counter-terrorism, etc. This paper is discussed theoretically and verified with the new method with experimental data.

Keyword: Microphones Array, Source Angle, Source Distance, Quick Estimation Algorithmtroduction

1. Introduction:

Array signal processing is widely used in communications, radar, sonar, medical, aerospace and other fields. At present, many countries have developed various types of equipment that can detect explosion site or location of shooting with the operations of counter-terrorism. The development of a number of acoustic positioning systems is due to visual orientation is difficult to realize in practice. Such as the U.S boomerang system, Israel's Rafael anti-sniper system and the small arms detection and location system called Ferret is researched by MacDonald, Dettwiler and Associates Corporation and Defense Research and Development Committee in Canada. Microsoft's Vista operating system support for MIC array processing and Intel's HD Audio specification allows 16 MIC, 32 KHz sampling, which provide a good support for acoustic array processing. In this paper, Sound Source Localization of MIC Array in plain environment use delay estimation algorithm, quasi-L1-related technology accelerates the speed of delay estimation, improved anti-outliers interference. Analysis of delay characteristics that applies to orientation segmentation improves the speed and the ability to remove the local extreme point. Optimization method solves millisecond location calculation in PC.

2. Fundamental

In order to simulate the source estimation in plains, assuming MIC array and the sound source are in the same plane.

---

[*] Corresponding author Tel.: +86-010-64880318.
E-mail address: fanjing@bistu.edu.cn

3 MIC System:

Equilateral triangle model is to obtain the high consistency of the direction sensitivity. It is shown in Fig.1:

O (0, 0) is the origin of coordinate. L is the triangle side length. R is the distance between the source p to the origin. r is the distance between the origin to the MIC, which, r=L/$\sqrt{3}$ =0.5773502L. Φ is the angle between the R and r, we can calculate the Φ and the R by delay difference between source and each MIC. MIC.a (r, π/2), MIC.b (r, 4π/3) and MIC.c (r, -π/6) are the polar coordinates of triangle.
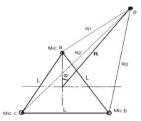

Figure 1.   3MIC Array Receiving System

R1, R2 and R3 are the distances between the source and each MIC, respectively: $R_1 = \sqrt{R^2 + r^2 - 2\,\mathrm{R}\,r\cos\Phi}$, $R_2 = \sqrt{R^2 + r^2 - 2\,\mathrm{R}\,r\cos(\frac{2\pi}{3} - \Phi)}$. D1, D2 and D3 are the distance differences between the source and each MIC, respectively: D1 = R2 – R1, D2 = R3 – R1, D3 = R3 – R2.

$$D_2 = \sqrt{R^2 + r^2 - 2\,\mathrm{R}\,r\cos(\tfrac{2\pi}{3} - \Phi)} - \sqrt{R^2 + r^2 - 2\,\mathrm{R}\,r\cos(\Phi)} \tag{1}$$

$$D_2 = \sqrt{R^2 + r^2 - 2\,\mathrm{R}\,r\cos(\tfrac{2\pi}{3} + \Phi)} - \sqrt{R^2 + r^2 - 2\,\mathrm{R}\,r\cos(\Phi)} \tag{2}$$

$$D_3 = \sqrt{R^2 + r^2 - 2\,\mathrm{R}\,r\cos(\tfrac{2\pi}{3} + \Phi)} - \sqrt{R^2 + r^2 - 2\,\mathrm{R}\,r\cos(\tfrac{2\pi}{3} - \Phi)} \tag{3}$$

Φ and R are calculated by simultaneous equations (1)(2), (2)(3) and (1)(3). Calculation of means of solution can reduce measurement error. We use Newton's method for finding approximations because equations are nonlinear. Optimization method that can improve calculation speed is as follows:

$$Error = \left| D_1 - d_1(\Phi, R) \right| + \left| D_2 - d_2(\Phi, R) \right| \tag{4}$$

Total error is the sum of absolute value of each error, where D1 and D2 are estimations of delay differences. We can calculate them by improved quasi-L1-relate algorithm. d1(Φ,R) is delay difference according to optimized adjust parameter Φ and R. Quasi-L1-relate algorithm not only do not need multiplications, but ignore the estimation of average amplitude, therefore operational efficiency is improved significantly.

It is shown in Fig.2, consider the sign and the value of delay difference, the circle is divided into six parts averagely, in order to prevent approximation of the local minimum.
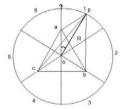

Figure 2.   Six Areas

Where, pa, pb and pc are the distances between the source p that may be at any point in the circle and each MIC. Let $D_1 = pb - pa$, $D_2 = pc - pa$. It is shown in TABLE I as follows:

TABLE I. THE RELATIONSHIP BETWEEN D1 AND D2

Section	Φ	D1	D2	Property
1	0^0 - 60^0	+	+	$|D_1|<|D_2|$
2	60^0 - 120^0	—	+	$|D_1|<|D_2|$
3	$120^0 - 180^0$	—	—	$|D_1|<|D_2|$
4	$180^0 - 240^0$	—	—	$|D_1|>|D_2|$
5	$240^0 - 300^0$	+	—	$|D_1|>|D_2|$
6	300^0 - 360^0	+	+	$|D_1|>|D_2|$

4 MIC System:

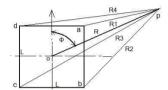Square model is to balance the estimated precision of each direction. It is shown in Fig.3:

Figure 3. 4MIC Array Receiving System

L is the square side length. MIC.a $(r, \pi/4)$, MIC.b $(r, 3\pi/4)$, MIC.c $(r, -3\pi/4)$ and MIC.d$(r, -\pi/4)$ are the polar coordinates of square. R1, R2, R3 and R4 are the distances between the source and each MIC, respectively:

$$R_1 = \sqrt{R^2 + r^2 - 2Rr\cos(\Phi - \tfrac{\pi}{4})} \ , \quad R_2 = \sqrt{R^2 + r^2 - 2Rr\cos(\tfrac{3\pi}{4} - \Phi)} \ , \quad R_3 = \sqrt{R^2 + r^2 - 2Rr\cos(\tfrac{5\pi}{4} - \Phi)} \ ,$$

$$R_4 = \sqrt{R^2 + r^2 - 2Rr\cos(\Phi + \tfrac{\pi}{4})} \ , \ D1, D2, D3 \ and \ D4 \ are \ the \ distance \ differences \ between \ the \ source \ and \ each \ MIC,$$

respectively: D1 = R2 – R1, D2 = R3 – R1, D3 = R4 – R1.

$$D_1 = \sqrt{R^2 + r^2 - 2Rr\cos(\tfrac{3\pi}{4} - \Phi)} - \sqrt{R^2 + r^2 - 2Rr\cos(\Phi - \tfrac{\pi}{4})} \qquad (1)$$

$$D_2 = \sqrt{R^2 + r^2 - 2Rr\cos(\tfrac{5\pi}{4} - \Phi)} - \sqrt{R^2 + r^2 - 2Rr\cos(\Phi - \tfrac{\pi}{4})} \qquad (2)$$

$$D_3 = \sqrt{R^2 + r^2 - 2Rr\cos(\Phi + \tfrac{\pi}{4})} - \sqrt{R^2 + r^2 - 2Rr\cos(\Phi - \tfrac{\pi}{4})} \qquad (3)$$

The method of finding approximations is to 3MIC system. $Error = |D_1 - d_1(\Phi, R)| + |D_2 - d_2(\Phi, R)| + |D_3 - d_3(\Phi, R)|$.
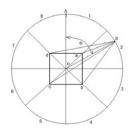

Figure 4. eight Areas

It is shown in Fig.2, the circle is divided into six parts averagely. $D_1 = pb - pa$, $D_2 = pc - pa$, $D_2 = pd - pa$. It is shown in TABLE I as follows:

TABLE II.   THE RELATIONSHIP BETWEEN D1, D2 AND D3

Φ	D1	D2	D3	Property
0^0 - 45^0	+	+	+	$\lvert D_1\rvert<\lvert D_2\rvert, \lvert D_3\rvert<\lvert D_2\rvert, \lvert D_3\rvert<\lvert D_1\rvert$
$45^0 - 90^0$	+	+	+	$\lvert D_1\rvert<\lvert D_2\rvert, \lvert D_3\rvert<\lvert D_2\rvert, \lvert D_3\rvert>\lvert D_1\rvert$
90^0 - 135^0	—	+	+	$\lvert D_1\rvert>\lvert D_2\rvert, \lvert D_3\rvert>\lvert D_2\rvert, \lvert D_3\rvert>\lvert D_1\rvert$
$135^0 - 180^0$	—	—	+	$\lvert D_1\rvert>\lvert D_2\rvert, \lvert D_3\rvert<\lvert D_2\rvert, \lvert D_3\rvert<\lvert D_1\rvert$
$180^0 - 225^0$	—	—	—	$\lvert D_1\rvert>\lvert D_2\rvert, \lvert D_3\rvert>\lvert D_2\rvert, \lvert D_3\rvert<\lvert D_1\rvert$
$225^0 - 270^0$	—	—	—	$\lvert D_1\rvert>\lvert D_2\rvert, \lvert D_3\rvert>\lvert D_2\rvert, \lvert D_3\rvert>\lvert D_1\rvert$
$270^0 - 315^0$	+	—	—	$\lvert D_1\rvert<\lvert D_2\rvert, \lvert D_3\rvert>\lvert D_2\rvert, \lvert D_3\rvert>\lvert D_1\rvert$
315^0 - 360^0	+	+	—	$\lvert D_1\rvert<\lvert D_2\rvert, \lvert D_3\rvert>\lvert D_2\rvert, \lvert D_3\rvert>\lvert D_1\rvert$

TABLE III.   THE RELATIONSHIP BETWEEN D1, D2 AND D3

Φ	D1	D2	D3	property
0^0 - 45^0	+	+	+	$D_3<=D_1$
$45^0 - 90^0$	+	+	+	$D_3>=D_1$
90^0 - 135^0	—	+	+	
$135^0 - 180^0$	—	—	+	
$180^0 - 225^0$	—	—	—	$D_3>=D_1$
$225^0 - 270^0$	—	—	—	$D_3<=D_1$
$270^0 - 315^0$	+	—	—	
315^0 - 360^0	+	+	—	

The angle range is only determined by comparing the sign and the value of D1, D2 and D3. Optimized estimation of two variables is more objectively effective.

3. Direction sensitivity

Now we discuss the MIC array sensitivity at direction. First we study just two MIC's situation. The following Figure 5 shows the case.
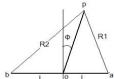

Figure 5.   Two MIC's direction sencitivity

Here a,b are MIC, P is sound source, o is mid-point. The delay can get for distance of R2 and R1, D(R,Φ) = R2(R,Φ)-R1(R,Φ). If D(R,Φ) change more when Φ change, the direction sensitivity is well. We need discuss the sensitivity stability for all direction.

$$D'(R, \Phi) = R2'(R, \Phi) - R1'(R, \Phi) = \frac{1}{2} * \frac{1}{\sqrt{R^2 + L^2 - 2RL\cos(\frac{\pi}{2} - \Phi)}} * \left(-2RL\sin\left(\frac{\pi}{2} - \Phi\right)\right)$$

$$- \frac{1}{2} * \frac{1}{\sqrt{R^2 + L^2 - 2RL\cos(\frac{\pi}{2} + \Phi)}} * \left(-2RL\sin\left(\frac{\pi}{2} + \Phi\right)\right) = -RL\left(\frac{\sin(\frac{\pi}{2} - \Phi)}{\sqrt{R^2 + L^2 - 2RL\cos(\frac{\pi}{2} - \Phi)}} + \frac{\sin(\frac{\pi}{2} + \Phi)}{\sqrt{R^2 + L^2 - 2RL\cos(\frac{\pi}{2} + \Phi)}}\right)$$

When $\Phi=0$, $D'(R，\Phi)=\dfrac{-RL}{\sqrt{R^2+L^2}}$, the absolute value is maximum, that means high sensitivity. When $\Phi=\dfrac{\pi}{2}$, $D'(R，\Phi)=0$, the sensitivity is minimum. The following figure6-(1) show the direction sensitivity, and at 3 dimension it is a ring.
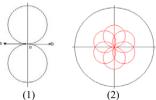

(1)   (2)

Figure 6.   3 MIC Sensitivity of direction

For Equilateral triangle, we can add three pairsensitivity together approximately. Fig.6-(2) show the result which show the direction sensitivity is nearly equation, it is a very good property.
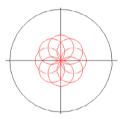
In 4 MIC case, the result as following:

Figure 7.   4 MIC Sensitivity of direction

The result also show the direction sensitivity is nearly equal.

4. Experimental Result

We use the idealized data to ensure the verification of the effectiveness and the accuracy. The pulse is present as follow:

We can calculate the distances and the delays to each MIC by the angles and the distances for setting the sound source are given. The algorithm is tested by output signal.

In this paper, experiments run on Pentium4 PC platform, sampling rate is 5000Hz, because the low sampling rate reduces the accuracy of angle estimation, computation and storage are increasing at the high rate.

Distance of each MIC is 1_M, R is 100 meters in Fig.1 and Fig.3.

TABLE IV.   EXPERIMENTAL RESULT

No.	ideal	3MIC	4MIC
1	00	1.280	-0.10
2	150	12.00	15.60
3	300	27.50	32.60

4	450	44.40	44.30
5	600	60.120	57.40
6	750	75.740	74.40
7	900	92.460	90.10
8	1050	104.560	104.40
9	1200	120.180	121.30
10	1350	136.040	136.50
11	1500	148.70	149.00
12	1650	168.80	167.00
13	1800	179.20	180.90
14	1950	193.30	196.00
15	2100	211.370	213.20
16	2250	224.10	226.50
17	2400	239.90	236.80
18	2550	255.70	254.00
19	2700	268.30	269.40
20	2850	284.40	283.10
21	3000	299.90	301.00
22	3150	315.70	314.00
23	3300	332.90	328.90
24	3450	348.10	3436.90

5. Conclusion:

The 4MIC system has the high positioning accuracy than the 3MIC to some extent. The 3MIC positioning system has been able to satisfy general requirements. The 3 MIC and 4 MIC all has very good direction sensitivity. In this paper, quasi-L1-related technology accelerates the speed of delay estimation, improved anti-outliers interference. Analysis of delay characteristics that applies to orientation segmentation improves the speed and the ability to remove the local extremum point. Optimization methods solve millisecond location calculation and satisfy calculation speed and precision requirements in Pentium4 PC platform in practice.

6. ACKNOWLEDGEMENT

References

[1] Dvorking T.V. Gannot S, Speaker Localization Using the unscented Kalman filter .*Proceedings of Hands Free Speech Communication and Microphone Arrays (HSCMA) Workshop*. Piscataway, NJ.USA,2005:3-4.

[2] Herbert B, Walter K, An acoustic human/machine interface with multi-channel sound reproduction , *IEEE International Workshop on Multimedia Signal Processing*, Cannes, France,2001:359-364.

[3] Seltzer M.L, Raj B, Speech-recognizer-based filter optimization for microphone array processing . *IEEE Signal Processing Letters* 2003; 10(3):69-71.

[4] Dibiase J, A high-accuracy, low-latency technique for talker localization in reverberant environments .*Brown University,Providence*,Phode Island USA.May 2000.

[5] Kumaresan R, Tufts D. W, Estimating the angels of arrival of plane waves .*IEEE Transactions on Aerospace and Electronic Systms* 1983;19(1):134-139.

[6] Valee S, Champagne B, Localization of wideband signals using least-squares and total Least-squares approaches .*IEEE Transactions od Signal Processing* 1999; 47(5): 1213-1222.

[7] Ju Tailiang, Research on Speech Source Localization Methods Based in Microphone Arrays . *University of Electronic Science and Technolgy of china*, 2006.

[8] Wu W, Hsieh C, Huang H, Hearing aid system with 3D sound localization. *IEEE Region 10 Conference*, TENCON,Taipei,2007:1-4

[9] Huang Y, Benesty J, Elko G.W, Passive acoustic source localization for video camera steering .*IEEE International Conference on Acoustics*, Speech, and Signal Processing, Istanbul, Turkey, 2000, 2:909-912.

[10] Zhang Yi, Yin Fuliang, Robust time-delay estimation in highly adverse acoustic environments. *Journal on Communications* 2008;5(19).