Localization Estimation of Sound Source by Microphones Array

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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.

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

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.

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

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

![Figure 1. 3MIC Array Receiving System](image)

R1, R2 and R3 are the distances between the source and each MIC, respectively: \( R_1 = \sqrt{R^2 + r^2 - 2Rr \cos \Phi} \), \( R_2 = \sqrt{R^2 + r^2 - 2Rr \cos \left(\frac{2\pi}{3} - \Phi\right)} \). D1, D2 and D3 are the distance differences between the source and each MIC, respectively: \( D_1 = R_2 - R_1, D_2 = R_3 - R_1, D_3 = R_3 - R_2 \).

\[
\begin{align*}
D_2 &= \sqrt{R^2 + r^2 - 2Rr \cos \left(\frac{2\pi}{3} - \Phi\right)} - \sqrt{R^2 + r^2 - 2Rr \cos \Phi} \\
D_2 &= \sqrt{R^2 + r^2 - 2Rr \cos \left(\frac{2\pi}{3} + \Phi\right)} - \sqrt{R^2 + r^2 - 2Rr \cos \Phi} \\
D_3 &= \sqrt{R^2 + r^2 - 2Rr \cos \left(\frac{2\pi}{3} + \Phi\right)} - \sqrt{R^2 + r^2 - 2Rr \cos \left(\frac{\pi}{3} - \Phi\right)} \\
\end{align*}
\]

\( \Phi \) 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:

\[
\text{Error} = |D_1 - d_1(\Phi, R)| + |D_2 - d_2(\Phi, R)|
\]

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. \( d_1(\Phi, R) \) is delay difference according to optimized adjust parameter \( \Phi \) 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](image)
Where, \( p_a, p_b \) and \( p_c \) are the distances between the source \( p \) that may be at any point in the circle and each MIC. Let \( D_1 = p_b - p_a \), \( D_2 = p_c - p_a \). It is shown in TABLE I as follows:

| Section | \( \Phi \) | \( D_1 \) | \( D_2 \) | Property |
|---------|-----------|---------|---------|----------|
| 1       | \( 0^\circ - 60^\circ \) | +       | +       | \( |D_1| < |D_2| \) |
| 2       | \( 60^\circ - 120^\circ \) | -       | +       | \( |D_1| < |D_2| \) |
| 3       | \( 120^\circ - 180^\circ \) | -       | -       | \( |D_1| > |D_2| \) |
| 4       | \( 180^\circ - 240^\circ \) | -       | -       | \( |D_1| > |D_2| \) |
| 5       | \( 240^\circ - 300^\circ \) | +       | -       | \( |D_1| > |D_2| \) |
| 6       | \( 300^\circ - 360^\circ \) | +       | +       | \( |D_1| > |D_2| \) |

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

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. \( R_1, R_2, R_3 \) and \( R_4 \) are the distances between the source and each MIC, respectively:

\[
R_1 = \sqrt{R^2 + r^2 - 2R r \cos(\Phi - \frac{\pi}{4})} , \\
R_2 = \sqrt{R^2 + r^2 - 2R r \cos(\frac{3\pi}{4} - \Phi)} , \\
R_3 = \sqrt{R^2 + r^2 - 2R r \cos(\frac{\pi}{4} - \Phi)} , \\
R_4 = \sqrt{R^2 + r^2 - 2R r \cos(\frac{5\pi}{4} - \Phi)} ,
\]

\( D_1, D_2, D_3 \) and \( D_4 \) are the distance differences between the source and each MIC, respectively:

\[
D_1 = R_2 - R_1, \\
D_2 = R_3 - R_1, \\
D_3 = R_4 - R_1.
\]

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

Figure 3. 4MIC Array Receiving System

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

| \( \Phi \) | \( D_1 \) | \( D_2 \) | \( D_3 \) | Property |
|-----------|---------|---------|---------|---------|
| 0° - 45°  | +       | +       | +       | \( |D_1|<|D_2|,|D_3|<|D_2|,|D_3|<|D_1| \) |
| 45° - 90° | +       | +       | +       | \( |D_1|<|D_2|,|D_3|<|D_2|,|D_3|<|D_1| \) |
| 90° - 135° | -       | +       | +       | \( |D_1|<|D_2|,|D_3|<|D_2|,|D_3|<|D_1| \) |
| 135° - 180° | -       | -       | +       | \( |D_1|<|D_2|,|D_3|<|D_2|,|D_3|<|D_1| \) |
| 180° - 225° | -       | -       | -       | \( |D_1|<|D_2|,|D_3|<|D_2|,|D_3|<|D_1| \) |
| 225° - 270° | -       | -       | -       | \( |D_1|<|D_2|,|D_3|<|D_2|,|D_3|<|D_1| \) |
| 270° - 315° | +       | +       | +       | \( |D_1|<|D_2|,|D_3|<|D_2|,|D_3|<|D_1| \) |
| 315° - 360° | +       | +       | +       | \( |D_1|<|D_2|,|D_3|<|D_2|,|D_3|<|D_1| \) |

The angle range is only determined by comparing the sign and the value of \( D_1 \), \( D_2 \) and \( D_3 \). 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.

\[
D(R, \Phi) = R_2(R, \Phi) - R_1(R, \Phi) = \frac{1}{2} \sqrt{R^2 + L^2 - 2RL \cos (\frac{\pi}{2} - \phi)} \left( -2RL \sin \left( \frac{\pi}{2} - \phi \right) \right) - \frac{1}{2} \sqrt{R^2 + L^2 - 2RL \cos (\frac{\pi}{2} + \phi)} \left( -2RL \sin \left( \frac{\pi}{2} + \phi \right) \right) = -RL \left( \frac{\sin (\frac{\pi}{2} - \phi)}{\sqrt{R^2 + L^2 - 2RL \cos (\frac{\pi}{2} - \phi)}} + \frac{\sin (\frac{\pi}{2} + \phi)}{\sqrt{R^2 + L^2 - 2RL \cos (\frac{\pi}{2} + \phi)}} \right)
\]
When $\Phi=0$, $D'(R, \Phi)=\frac{RL}{\sqrt{R^2+L^2}}$, the absolute value is maximum, that means high sensitivity. When $\Phi=\frac{\pi}{2}$, $D(R, \Phi) = 0$, the sensitivity is minimum. The following figure 6-(1) show the direction sensitivity, and at 3 dimension it is a ring.

![Figure 6. 3 MIC Sensitivity of direction](image)

For Equilateral triangle, we can add three pairs sensitivity 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](image)

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:

![Waveform](image)

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 $1m$, R is 100 meters in Fig.1 and Fig.3.

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

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