College of Science and Engineering, Zhejiang University

A Surveillance System for Drone Localization and Tracking Using Acoustic Arrays

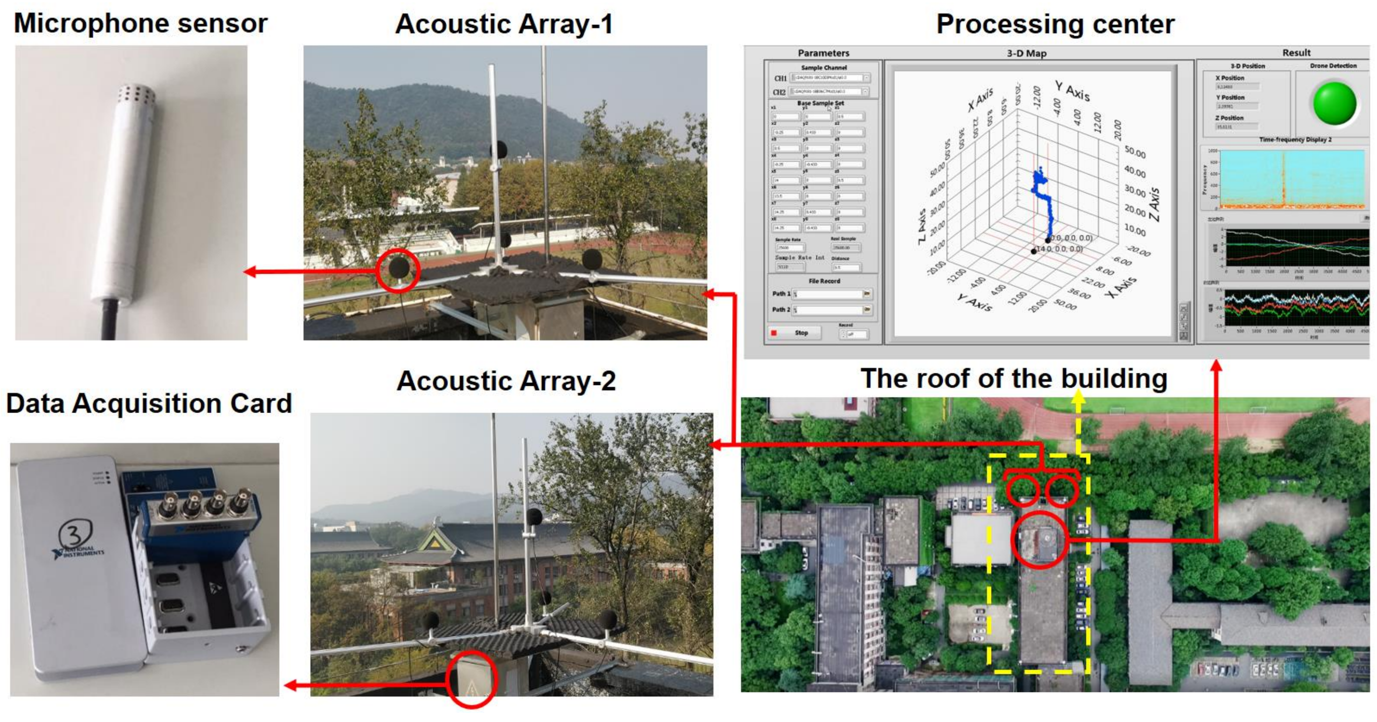
Xianyu Chang, Chaoqun Yang, Junfeng Wu, Xiufang Shi and Zhiguo Shi

Ⅰ. Abstract

The wide proliferation of drones has posed great threats to personal privacy and public security, which makes it urgent to monitor the drones in the sensitive areas. In this paper, we develop a systematic method for drone localization and tracking by using acoustic arrays. Specifically, we develop a time difference of arrival (TDOA) estimation algorithm based on Gauss priori probability density function to overcome the multipath effect and the low signal-to-noise ratio (SNR), and design a localization method by making full use of the TDOA estimation results, followed by tracking the drone by Kalman filter.

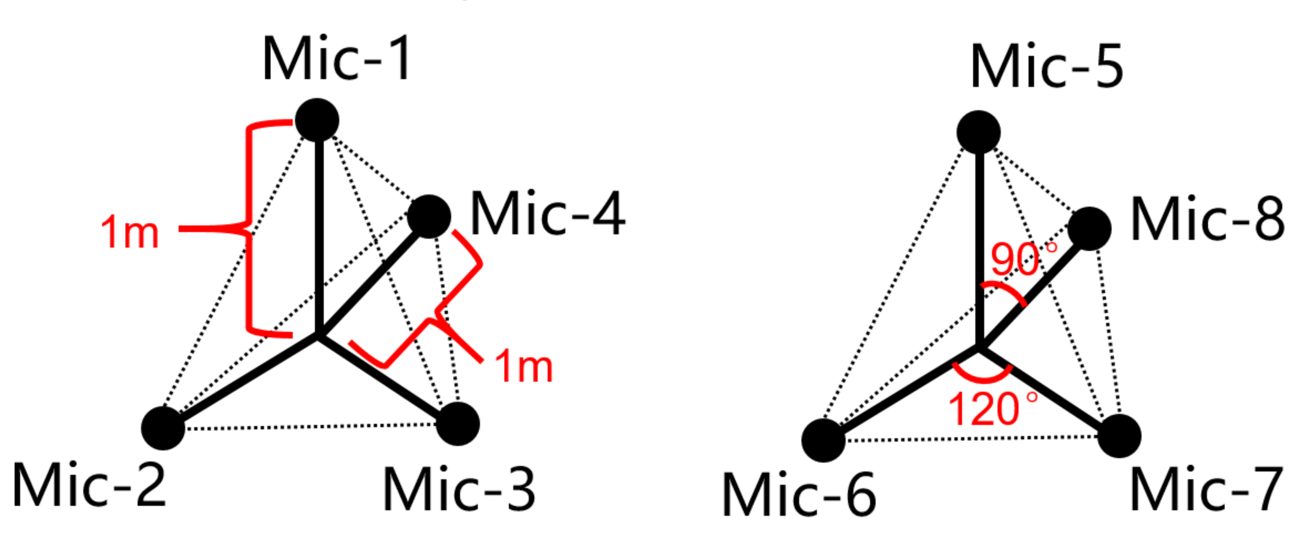
Ⅱ. System deployment

A. System overview



The system consists of two tetrahedron-shape acoustic arrays and a processing center. The acoustic arrays are used to sample the surrounding acoustic signal periodically and the processing center is used to control acoustic signal sampling, to access the data and to run the localization and tracking algorithms.

B. Acoustic array model



The acoustic array model consists of two acoustic arrays. The distance between the two acoustic arrays is 14m. All the sensors have been waterproof treated in order to work well under rain and snow weathers. Meanwhile, windproof covers have been installed on every microphone sensors to weaken the influence of low frequency wind noise.

Ⅲ. Drone localization and tracking methods

A. TDOA estimation

The GCC-PHAT is used to calculate the TDOA:

$$R_{x_m x_n}(\tau,k)=\int_{-\infty}^{\infty} G_{x_m x_n}(f)\varphi_{mn}(f)e^{-j2\pi f\tau}df$$

We construct a GPDF as following:

$$G_{\mathrm{PDF}}(\tau,k)=\frac{1}{\sqrt{2\pi\sigma}}e^{-\frac{(\tau-\mu)^2}{2\sigma^2}}$$

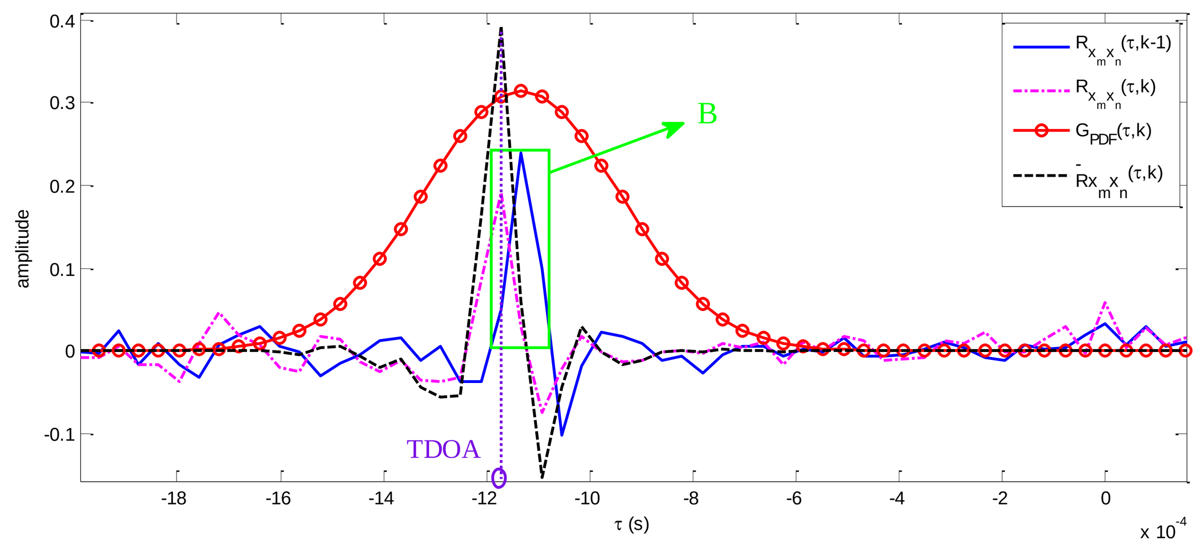
$$\mu=\tau_{mn}(k-1)\quad \sigma^2=\frac{\sum_{i,\tau_i\in B} R_{x_m x_n}(\tau_i,k-1)(\tau_i-\mu)^2}{\sum_{i,\tau_i\in B} R_{x_m x_n}(\tau_i,k-1)}$$

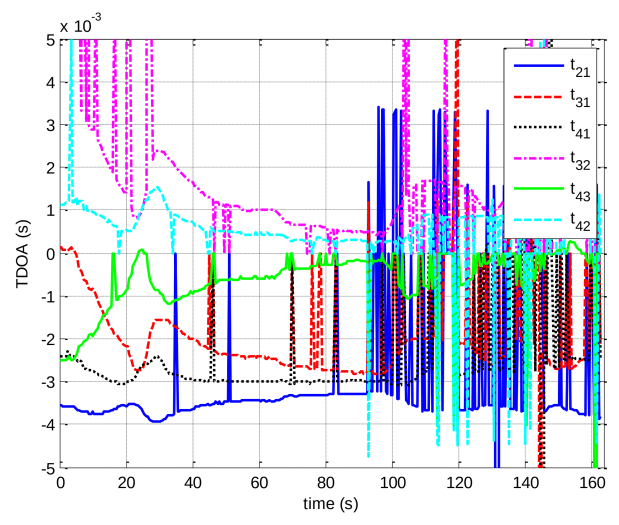
The new CPDF at time k can be given by:

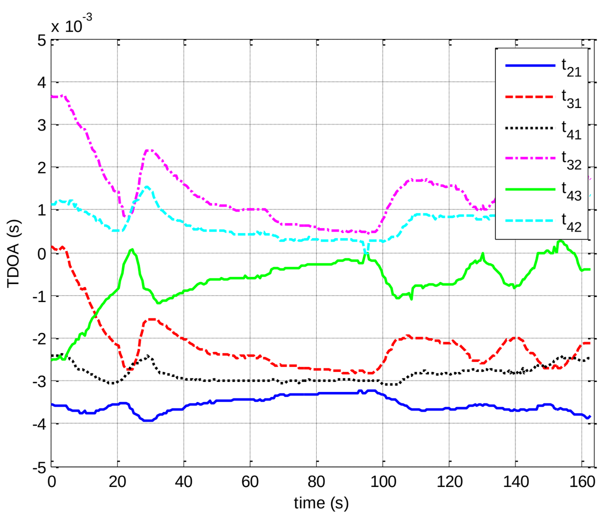
$$\tilde{R}_{x_m x_n}(\tau,k)=G_{\mathrm{PDF}}(\tau,k)R_{x_m x_n}(\tau,k)$$

The TDOA result at time k can be given as:

$$\tau_{mn}(k)=\mathrm{argmax}\,\tilde{R}_{x_m x_n}(\tau,k),\tau\in[-d/c,d/c]$$







B. Drone localization and tracking

According to sensor pair Mic-m and Mic-n:

$$d_{mn}=\|S_m-S_0\|-\|S_n-S_0\|$$

We can transform the equation as:

$$\begin{bmatrix}2(S_m-S_n) & 2d_{mn}\end{bmatrix}\begin{bmatrix}S_0^T\\ d_{n0}\end{bmatrix}=S_mS_m^T-S_nS_n^T-d_{mn}^2$$

Then we can write:

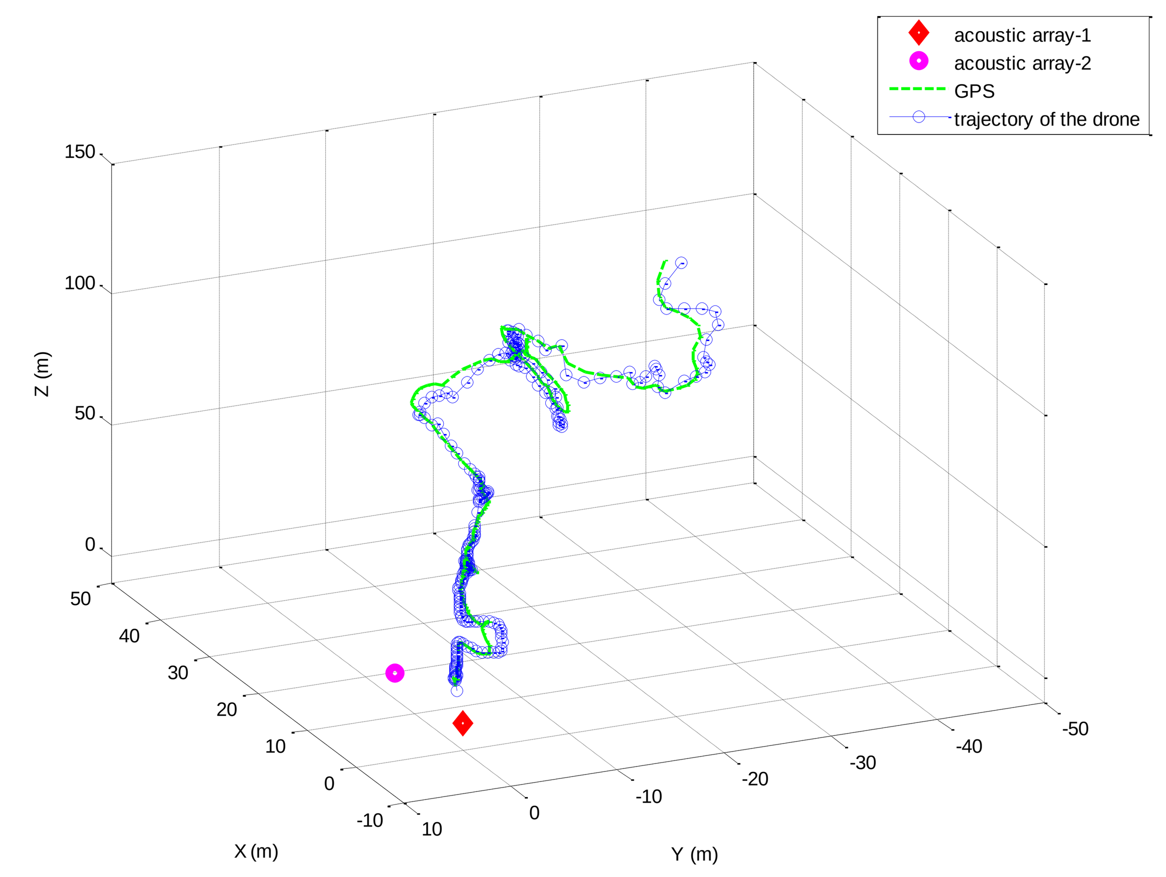
$$A=2\begin{bmatrix}S_2-S_n & d_{2n} & 0\\ S_3-S_n & d_{3n} & 0\\ S_4-S_n & d_{4n} & 0\\ S_6-S_{\tilde{n}} & 0 & d_{6\tilde{n}}\\ S_7-S_{\tilde{n}} & 0 & d_{7\tilde{n}}\\ S_8-S_{\tilde{n}} & 0 & d_{8\tilde{n}}\end{bmatrix}\qquad B=\begin{bmatrix}S_2S_2^T-S_nS_n^T-d_{2n}^2\\ S_3S_3^T-S_nS_n^T-d_{3n}^2\\ S_4S_4^T-S_nS_n^T-d_{4n}^2\\ S_6S_6^T-S_{\tilde{n}}S_{\tilde{n}}^T-d_{6\tilde{n}}^2\\ S_7S_7^T-S_{\tilde{n}}S_{\tilde{n}}^T-d_{7\tilde{n}}^2\\ S_8S_8^T-S_{\tilde{n}}S_{\tilde{n}}^T-d_{8\tilde{n}}^2\end{bmatrix}$$

$$X_{Los}=\begin{bmatrix}S_0^T\\ d_{n0}\\ d_{\tilde{n}0}\end{bmatrix}=(A^TA)^{-1}A^TB=\begin{bmatrix}x & y & z & d_{n0} & d_{\tilde{n}0}\end{bmatrix}^T$$

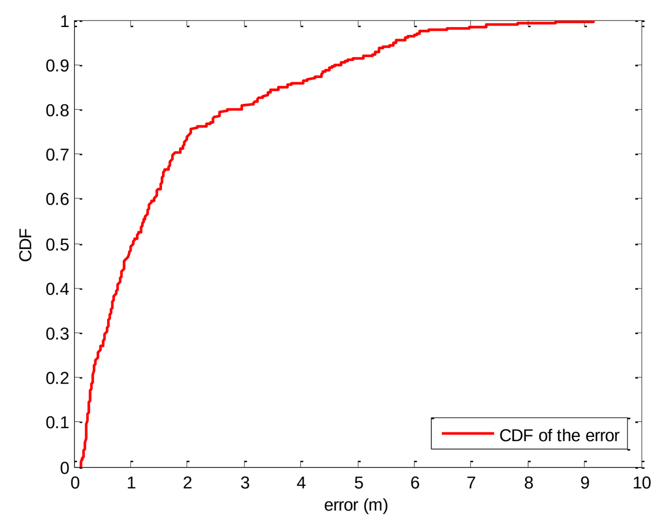
The final location of the drone can be obtained as:

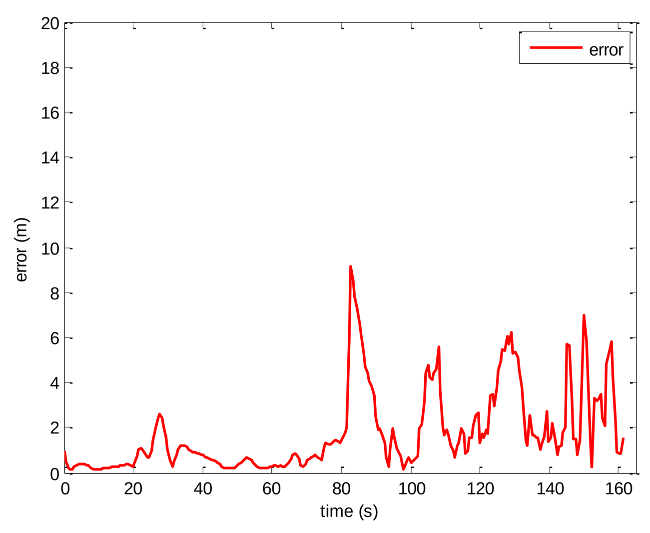
$$\hat{S}^{k+1}=\hat{S}^k+\left(F_s^TS_{\mathrm{cov}}^{-1}F_s+\lambda I\right)^{-1}F_s^TS_{\mathrm{cov}}^{-1}(T-F)$$

Apply Kalman filter to get the drone's trajectory.



Ⅳ. Conclusion





The longest distance has reached more than 100m with the SNR lower than -5dB. From these two figures, we can see that more than 95% of the estimation errors are lower than 6m and 80% of the estimation errors are within 2m.