DOA Estimation Using Amateur Drones Harmonic Acoustic Signals

Chaoqun Yang, Zexian Wu, Xianyu Chang, Xiufang Shi, Junfeng Wu and Zhiguo Shi
Anti-UAV Group, State Key Lab. of Industrial Control Technology, Zhejiang University, China

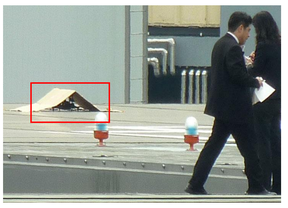
Abstract

In this paper, we consider the problem of the direction-of-arrival (DOA) estimation of amateur drones.

- We formulate the acoustic signals of amateur drones by a harmonic model;
- We improve MUSIC algorithm under the harmonic model to estimate the DOAs of amateur drones;
- We conduct a real-life drone tracking platform integrating the algorithm to track amateur drones.

Security Threats About Amateur Drones Intrusions

Drone crash-landed in front of the German Chancellor in Sept. 2013.



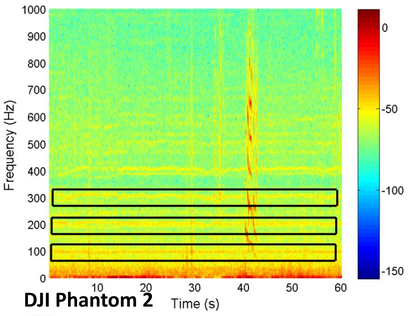
Drone landed on the roof of the Japanese Prime Minister's office in April 2015.

Drone crashed on the South Lawn of the White House in Jan. 2015.

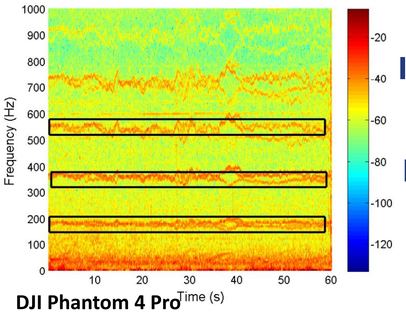
Drone flew in the vicinity of Hangzhou International Airport in Jan. 2017.

Harmonic Model Formulation of Drone Acoustic Signals

Time-frequency



DJI Phantom 2



DJI Phantom 4 Pro

Model acoustic signals as the sum of harmonics

$$x_m(k) = \sum_{p=1}^{P}\sum_{i=1}^{N} d_{ip}(k)\gamma_i^k \kappa_{ip}^{m-1} + v_{mp}(k)$$

x_m:The received signal of m-th sensor

d_{ip}:The Fourier coefficient of p-th drone associated with i-th harmonic

$\gamma_i = e^{j2\pi f_i}, \kappa_{ip} = e^{-j2\pi f_i \Delta \sin\theta_p/c}$

f_i: The frequency corresponding to i-th harmonic of p-th drone

P: The number of amateur drone N: The number of harmonics

v_{mp}: Spatially and temporally white Gaussian noise

In a vector form

$$x(k) = As(k) + v(k)$$

DOA estimation problem of drones is formulated

Given K snapshots of data vector $x(k)$, estimate θ_p for $p = 1, \dots, P$.

DOA Estimation By Using MUSIC Algorithm Under Harmonic Model

Theorem: A and $U_{M\times Q}$ are orthogonal as $a_j^H(\theta)U_{M\times Q} = 0$, where a_j is the j-th column of A, $U_{M\times Q}$ is the eigenvectors associated with $Q = M - NP$ smallest eigenvalues of $R(k) = E[x(k)x^H(k)]$, and $j = 1, \dots, NP$.

Search the peaks in the following cost function

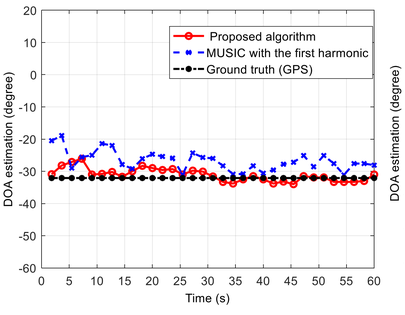
$$P(\theta) = \frac{1}{\sum_{j=1}^{N} a_j^H(\theta)U_{M\times Q}U_{M\times Q}^H a_j(\theta)}$$

Real-life Drone DOA Tracking Experiments

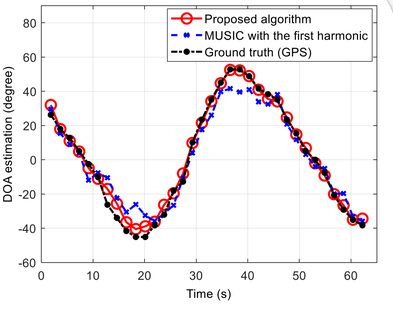
The deployed acoustic ULA

Acoustic sensor

NI data acquisition card



DOA estimation results when DJI Phantom 4 is hovering still



DOA estimation results when DJI Phantom 4 is flying in parallel relative to the ULA