AIM: Acoustic Inertial Measurement
For Indoor Drone Localization and Tracking

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Emerging Indoor Drone Application

Indoor Warehouse

Inventory

Logistics

Surveillance
Dilemma of Indoor Drone Tracking

**GPS-denied**
- **IMU-based methods**
  - suffer from **error accumulation** due to lack of absolute coordinate.

**Rich mutipath**
- **RF-based methods**
  - suffer from **signal distortion** due to rich multipath on metal.

**Frequent NLoS**
- **Infrared-based methods**
  - suffer from **target loss** due to frequent NLoS
Our Method

An acoustics based inertial measurement working in both LoS and NLoS.

- **Mean Error**
  - 1.43m in LoS
  - 1.89m in NLoS

- **Error Comparison**
  - 46% less than UWB in NLoS
  - 57% less than GPS in outdoor
Different motions lead to unique dynamics of propellers and fuselage.
Unique dynamics of propellers lead to distinct acoustic features.
AIM Overview

**Acoustic Inertial Measurement**
with both frequency and spatial domain

<table>
<thead>
<tr>
<th></th>
<th>Frequency domain</th>
<th>Spatial domain</th>
<th>Single Peak</th>
<th>Multiple Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unstable DoA</strong></td>
<td>Vertical linear</td>
<td></td>
<td></td>
<td>Horizontal linear motion</td>
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<tr>
<td></td>
<td>motion</td>
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**Entirely passive scheme**  
**Work across LoS & NLoS**
**Scalable to arbitrary range**
**No hardware modification**
The drag force: $T_i^v = k f_i^2$

The sound heard: $f_i^{BPF} = n f_i$

The sound can be quantified based on drone’s structure.
Observation

Hovering Motion
\[ f_1 = f_2 = f_3 = f_4 \quad v=0 \]

Yaw Motion
\[ f_1 = f_3, f_2 = f_4 \]

Vertical Motion
\[ f_1 = f_2 = f_3 = f_4 \]

Horizontal Motion
\[ f_1 = f_4, f_2 = f_3 \]

How to disambiguate motions with the same number of frequency band?
## Motion Identification Scheme

Disambiguate motions with information in spatial domain

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How to find the exact coordinates?
In both dynamic equations, the only unknown quantity is the height $h_{t+1}$.

For more detail, please refer to our paper.
Tracking in NLoS

Smoothed NLoS azimuth always indicates whether NLoS appears.
Evaluation

Microphone Array
- 6-Mic Array
- 4-Mic Array
  (Sampling rate: 48kHz)

Baseline
- UWB Node
- Infrared Camera
  (Fixed on the tripods)

DJI mini 2 Quadcopter
  (Weight: 249g  BPF: 328Hz)

Horizontal motions:
- Fly along the distance maker.
- Keep vertical coordinates unchanged.

Vertical motions:
- Climb or descent to a certain height.
- Keeping horizontal coordinates unchanged.

Experiment area

Distance Marker
  (Imaged by the drone's camera)
AIM outperforms LinkTrack 46% in NLoS with a mean error of 1.89 m. AIM can constantly provide location updates when OptiTrack is down.
Impact of Environment Noise

AIM is robust to moderate noise sources in the environment.
Deployment in Real Warehouse

AIM outperforms UWB in the real warehouse environment
AIM can extend to any range yet accuracy never degrades drastically. AIM can function outdoors and outperform GPS 57% in 2D tracking.
**Summary**

- **AIM** is the first-of-its-kind passive indoor drone tracking technique that works with a single 2D microphone array.

- The core innovation is that we explore **acoustics-based dynamics**, which bridges the drone’s dynamics equations and acoustic features.

- AIM is able to localize a drone in any range and layout, with the mean errors **46%** less than UWB indoors and **57%** less than GPS outdoors.
Thank You!