Towards airborne seismic

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Research goal

measure a strong motion signal from an airborne platform
Proposed method

Monitor ground motion from an UAV using cameras
Successful scenarios

Rapstine, Sava, & Arias (2017)
Successful scenarios

Rapstine, Sava, & Arias (2017)

no drone motion

known drone motion

Rapstine, Sava, & Arias (2017)
Assumptions

Past work:
exact platform motion

Present work:
noisy observations of platform motion
Assumptions

Past work: exact platform motion

Present work: noisy observations of platform motion
Assumptions

Past work: ✓
exact platform motion

Present work:
noisy observations of platform motion
Research question

What is the **character** of noise in UAV motion observations?

Is noise ...  
white?  
uncorrelated?  
Gaussian?  
band-limited?  
sparse?

“noise character”
Research question

Unmanned Aerial Vehicle (UAV) motion monitored by onboard sensors

What type of noise is in observed UAV motion?

Position: X, Y, Z
Orientation: $\phi, \theta, \psi$
# Noise measurement experiment

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>stationary motion sensor</td>
<td>Position: X, Y, Z</td>
</tr>
<tr>
<td>1 hour of noise observations</td>
<td>Orientation: $\phi$, $\theta$, $\psi$</td>
</tr>
<tr>
<td>~3,600,000 samples</td>
<td>acquisition by Honeywell (2018)</td>
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Noise time series
Is noise white?

Noise is not white
Is noise Gaussian?

Positional noise is **not** Gaussian.
Is noise Gaussian?

Orientational noise is **not** Gaussian.
Is noise band limited?
Is noise band limited?
Is noise band limited?
Is noise band limited?

Z-position

more white higher noise

less white lower noise
Is noise band limited?

Positional noise is **not** band limited
Is noise band limited?
Is noise band limited?

broadband signal observed at 900 seconds

sensor rotation?
Is noise band limited?
Is noise band limited?

The image shows a spectrogram with time on the x-axis, frequency on the y-axis, and dB-degree on the right side. The question of whether noise is band limited is posed.
Is noise band limited?

broadband signal observed at 900 seconds
Is noise band limited?

Orientation noise behavior less time variant than position noise
Is noise band limited?

UAV motion observation noise is not band limited
Is noise correlated?

Positional noise is correlated
Research question

What is the character of noise in UAV motion observations?

Is noise …

- white? ✗
- uncorrelated? ✗
- Gaussian? ✗
- band-limited? ✗
- sparse?
Research question

What is the **character** of noise in UAV motion observations?

Is noise …

- white?  
- uncorrelated?  
- Gaussian?  
- band-limited?  
- **sparse**?

In what domain does signal appear sparse?
Is the noise sparse?
Is the noise sparse?
Is the noise sparse?

Wavelets sparsely represent piecewise smooth functions.

noise signal reconstruction using 10% of wavelets
Concluding insight

What is the **character** of noise in UAV motion observations? comparable to ground motion signal
non-white
non-Gaussian
time varying
correlated
sparse
Future steps

Use data to discover sparse domains

Key challenges
Finding incoherent sparse domains for both signal and noise
Backup slides
Independent Component Analysis (ICA)

Find a matrix that best separates observations into statistically independent sources by minimizing an objective function.

\[
\min_W \phi(W) = H(X) - H(X \mid Y)
\]

*information content difference after observations*

\[X = WY\] : separated source 1 and 2

\[Y = XM\] : observation of mixed sources

(See Amari et al. 2006 for derivation)
Is noise correlated?
Is noise correlated?
Is noise correlated?
Seismic signal vs. platform motion

Measure this....

... from a platform moving like this.

UAV motion

ground motion
UAV motion and ground motion are mixed

... from an onboard sensor ...

... and from a camera.

IMU = Inertial measurement unit
How are these signals different?

- **ground motion**
- **UAV motion**
How are these signals different?

Disclaimer: *individually* rescaled frequency spectra for plotting. (UAV motion is actually much higher energy than ground motion)
“Given large amounts of data, learn a non-linear mapping from available inputs to valuable outputs”
Machine learning

“Given large amounts of data, **learn** a non-linear **mapping** from available inputs to valuable outputs”

Available inputs: “features” or “data”

The machine: Non-linear mapping

Valuable outputs: “labels” or “predictions”
“Given large amounts of data, learn a non-linear mapping from available inputs to valuable outputs.”

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Machine learning

“Given large amounts of data, learn a non-linear mapping from available inputs to valuable outputs”

Available inputs:
- IMU data
- LDV data
- Stereo vision data

The machine:
- Non-linear mapping
- Signal separation

Valuable outputs:
- ground motion
“Given large amounts of data, learn a non-linear mapping from available inputs to valuable outputs.”

Major requirement: require network that handles variably-sized inputs

Recurrent Neural Networks (RNNs) do this :)