Decoding Golden Eagle Movement Behavior From High-Resolution, Variable-Rate Telemetry Data Through Bayesian Filtering

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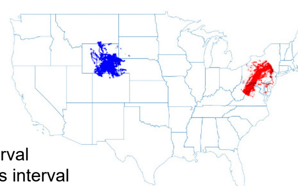
Objective: Understand behavioral response of golden eagles to fine-scale spatiotemporal variations in atmospheric, topographical, time-lagged, and look-ahead factors using telemetry data.

Solution: Bayesian filtering and calibration tool that relies on (1) Kalman filtering for resampling that variable-rate data at 1 Hz, (2) Automatic Relevance Determination (ARD) algorithm for identifying relevant covariates, (3) Bayesian inference approach to include uncertainty information on covariates and positional telemetry data.

Telemetry Data

Acquired by Conservation Science Global from golden eagles tagged with solar-powered GPS units from Cellular Tracking Technologies

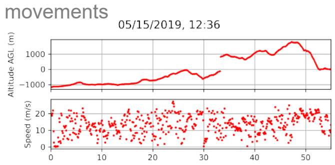
Western U.S.:
38 golden eagles
3.5 million points
March 2019–May 2020
45 wind power plants
2,500 active turbines
Variable sampling rate
- 63% data at 6-s interval
- 80% data under 10-s interval



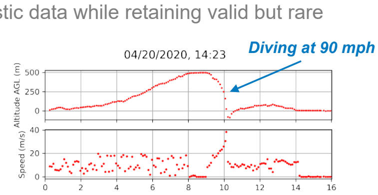
Eastern U.S.:
75 golden eagles
0.6 million points
Feb 2009–Dec 2020
65 wind power plants
1,800 active turbines
Variable sampling rate
- 13% data at 6-s interval
- 50% data under 30-s interval

Data Processing

Removing false fixes and other unrealistic data while retaining valid but rare movements



False Fixes: Sharp change in altitude above ground level (AGL) or consistently negative AGL



Valid movement: Sharp decline in AGL along with high horizontal speed

Track Identification

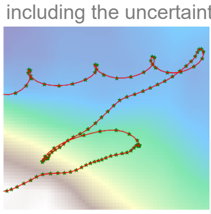
Classifying telemetry data into individual tracks based on a set criterion

- Each track has time sampling rate less than 10 seconds
- Each track has total time duration larger than 4 minutes

	Western U.S.	Eastern U.S.
% of data used	56.6%	21%
Number of tracks	5,555	413
Total time duration	3,870 hours	272 hours
Median track length	21 min	17 min

Kalman Filtering

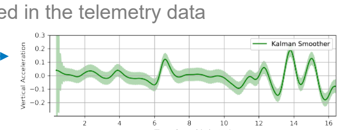
Resampling each track at a constant 1-Hz rate using Kalman Smoother while including the uncertainty information captured in the telemetry data



Stochastic Constant Acceleration Model

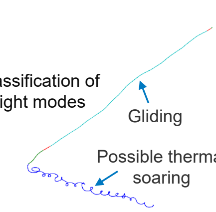
$$\dot{x} = \frac{d}{dt}\begin{Bmatrix}p\\ v\\ a\end{Bmatrix} = \begin{Bmatrix}v\\ a\\ \epsilon\end{Bmatrix} \text{ where } \epsilon \sim \mathcal{N}(0, \sigma^2)$$

Access to acceleration data



Movement dynamics
- x position
- y position
- Vertical speed
- Horizontal speed
- Heading
- Heading rate
- Horizontal tangential acceleration
- Vertical acceleration
- Horizontal radial acceleration
- Radius of curvature
- Flight mode

Classification of flight modes

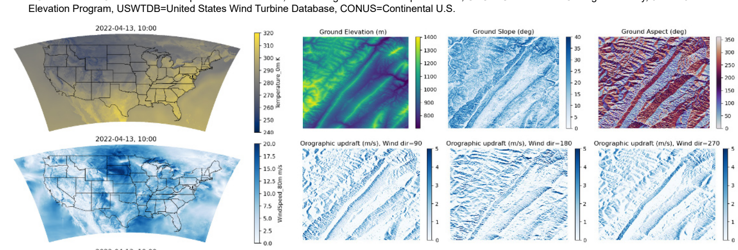


Data Annotation

Annotating each point in the resampled tracks with atmospheric and topographical entities

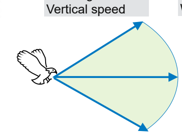
- Atmospheric covariates obtained from NOAA's HRRR data (3 km, hourly, CONUS)
- Topographical covariates obtained from USGS's 3DEP data (10 m, CONUS)
- Turbine-related covariates obtained from USGS's USWTDB data (updated monthly)

NOAA=National Oceanic and Atmospheric Administration, HRRR=High Resolution Rapid Refresh, USGS=United States Geological Survey, 3DEP=3D Elevation Program, USWTDB=United States Wind Turbine Database, CONUS=Continental U.S.



Time-lagged	Atmospheric	Topographical
5 & 10 s ago	At current location	At current location
Altitude AGL	Orographic updraft	Ground elevation
Horizontal speed	Deardorff velocity	Ground slope
Heading rate	Wind speed at 80 m	Surface roughness
Vertical speed	Wind shear	Time of day

For low AGL flight, orographic updrafts are computed at



10 & 45 degrees away
50 & 100 m ahead

Bayesian Calibration

Using ARD regression to identify relevant covariates, and computing the posterior distribution of corresponding weights

$$Y_{k+1} = \sum w_j X_{j,k} + \epsilon_i$$

Algorithm:
1. Each covariate is standardized using quantile transformer
2. Assign a zero-mean Gaussian prior distribution to all weights, with each weight having its own standard deviation
3. Using Type-II maximum likelihood, identify the relevant weights, i.e. weights with non-zero mean of the posterior distribution
4. Prune the irrelevant covariates and use the posterior distribution of weights of relevant covariates to obtain predictions

Results

Western U.S., orographic soaring: Vertical movements are more dependent on orographic updrafts at the current location than the updrafts nearby

Eastern U.S., orographic soaring: Vertical movements are more dependent on orographic updrafts 50 m ahead in the direction of movement, rather than the updrafts at the current location or 100 m ahead

Persistence: Higher persistence in thermal soaring and gliding flight than in orographic soaring

Affect of atmospheric conditions: Ground features deemed irrelevant by ARD for gliding and thermal soaring flight

Conclusions:

- Uncertainty quantifying Bayesian filtering and calibration framework to handle telemetry data
- Inclusion of look-ahead covariates provide deeper insight into fine-scale decision-making of golden eagles

Next Steps:

- Validation of the calibrated model using high-resolution telemetry data from new GPS units
- Investigating turbine avoidance behavior, if any

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