An AI-based 3D Bat Movement Tracking System at Wind Energy Facilities using Multi-Thermal Video Cameras

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NAWEA, Track: Digitalization, AI, Machine Learning

Session: Digital Solutions for Efficient and Secure Wind Energy

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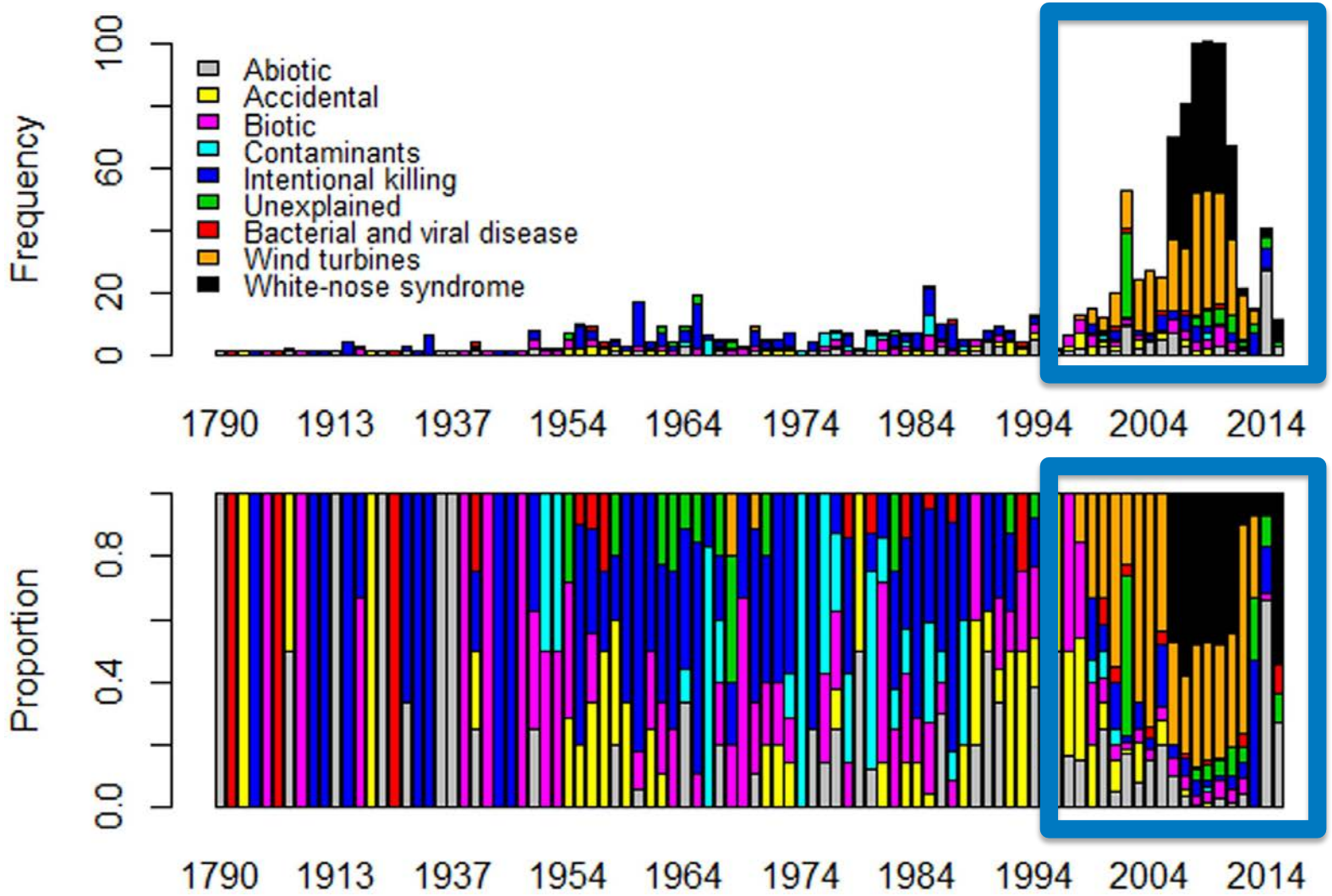
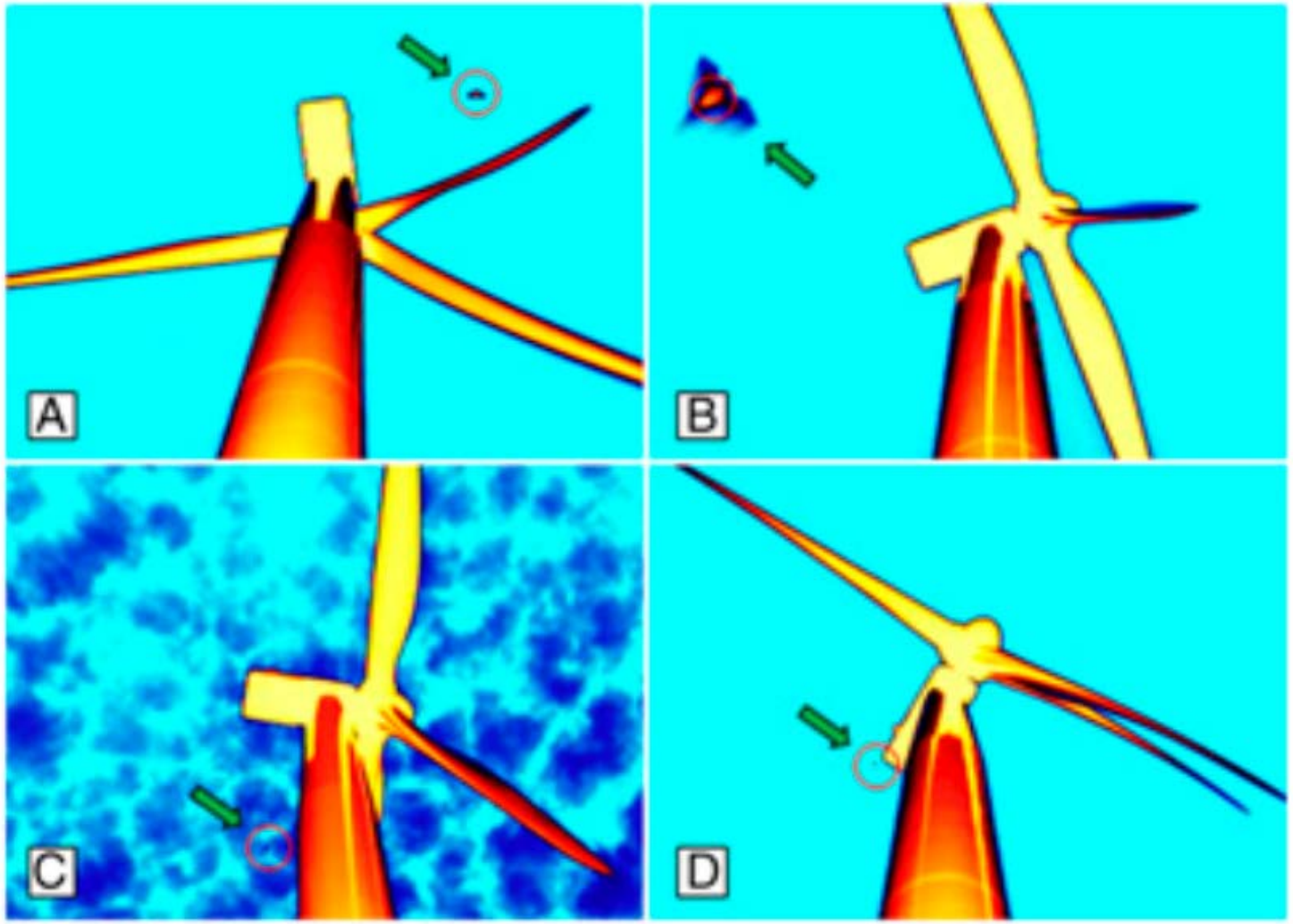
Growing Concerns of Increased Bat Mortalities



- Starting 2000s, the global increase of industrial wind-power facilities significantly contributed to bat mortality causes, but we don't know why!
- Why bat collision matters?
  - Bats are important for ecosystems, providing services like pest control and pollination.
  - Need to conserve bat population and endangered species
  - Accumulative collision can damage the wind turbine blade
- We need to understand the bat behavior and interactions with turbines to prevent collision!

O'Shea, T.J., Cryan, P.M., Hayman, D.T.S., Plowright, R.K. and Streicker, D.G. (2016), **Multiple mortality events in bats.** Mammal Review, 46: 175-190. https://doi.org/10.1111/mam.12064

Cost-Effective Strategy to Monitor Bat Activities



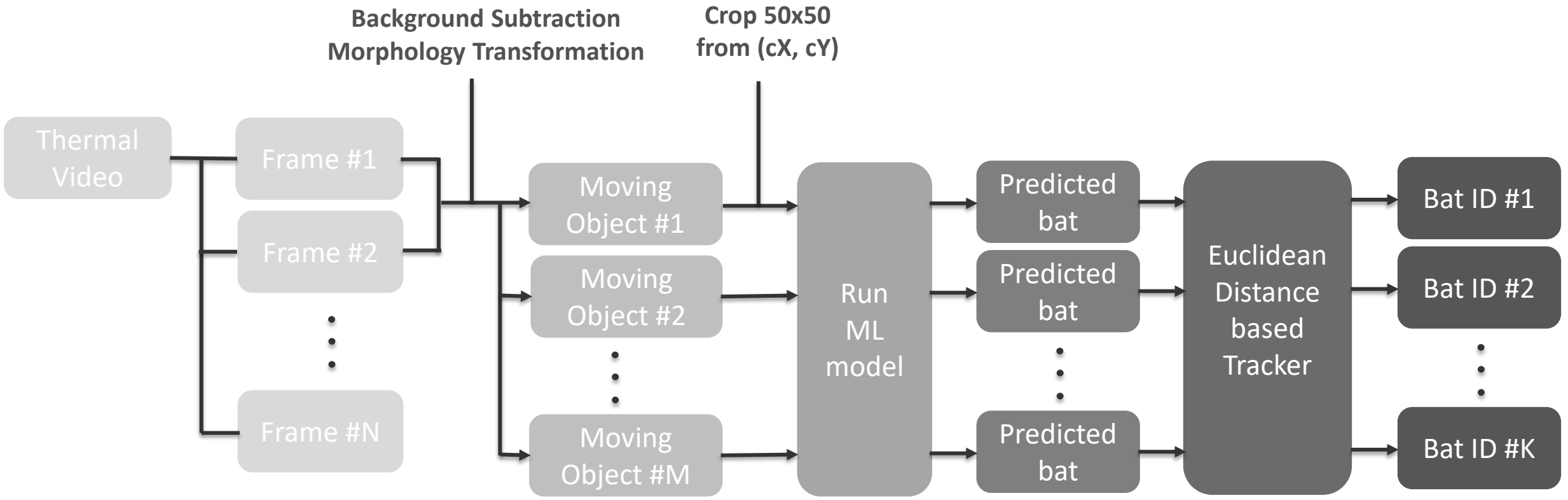
- Manual review from bat experts
  - Thermal video cameras (**1,304 hours**)
- Need Cost-Effective Monitoring method which is:
  - Fast
  - Consistent
  - Long-term
  - Easy-to-implement
  - Broadly-scalable

Behavior of bats at wind turbines, Paul. M. Cryan et al. Proceedings of the National Academy of Sciences Oct 2014, 111 (42) 15126-15131; DOI:10.1073/pnas.1406672111

Set Up Thermal Cameras at NREL Flatirons

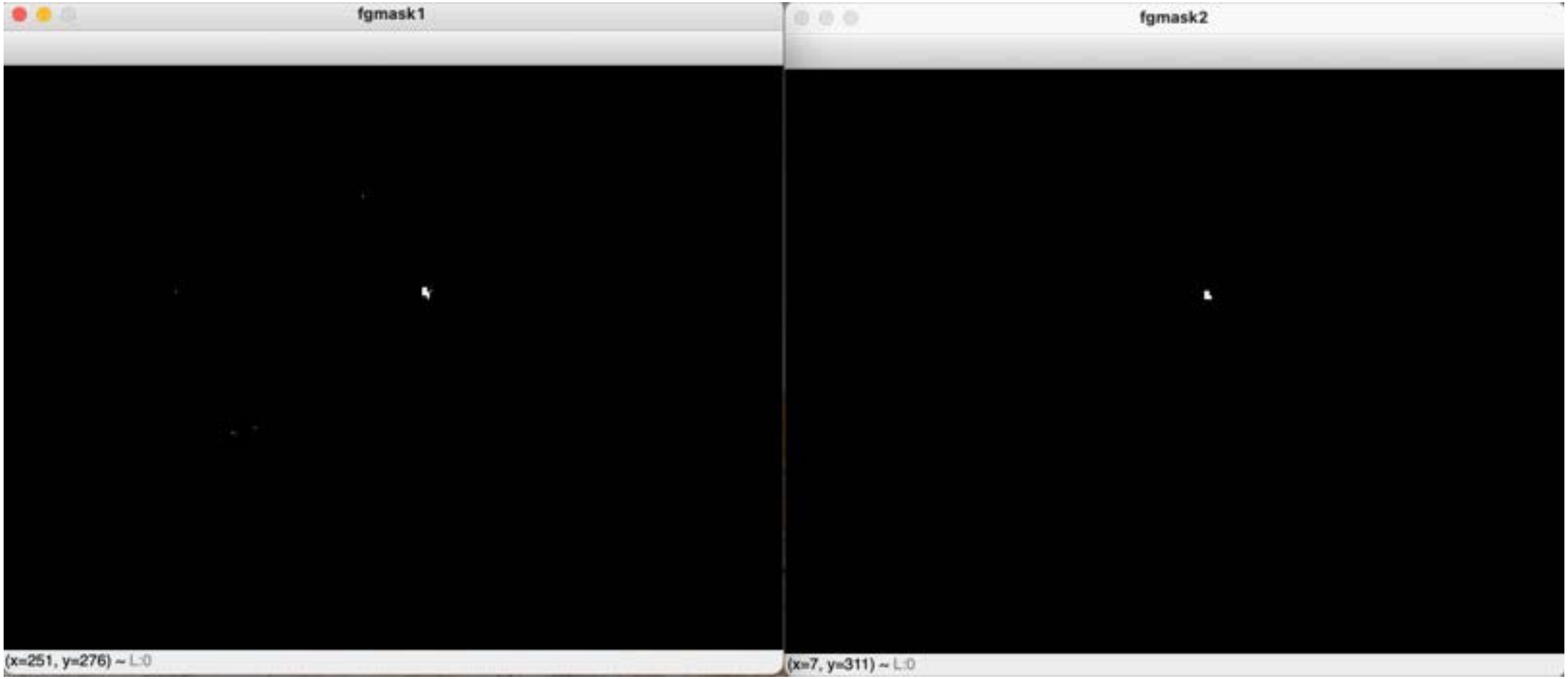
- Each sensors are:
  - 70.25 inches off the ground
  - 37.5 inches apart
  - pointing up at the blade
  - Matched timestamps using GPS module

2D Bat Monitoring Methodology: Identifying bats



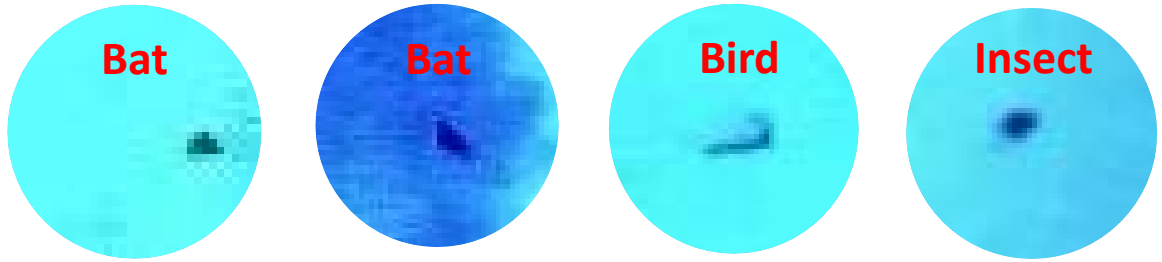
Only focus on large moving objects!

- Remove the noise from background, using additional image processing techniques – erosion, dilation.



How to distinguish bat from others?

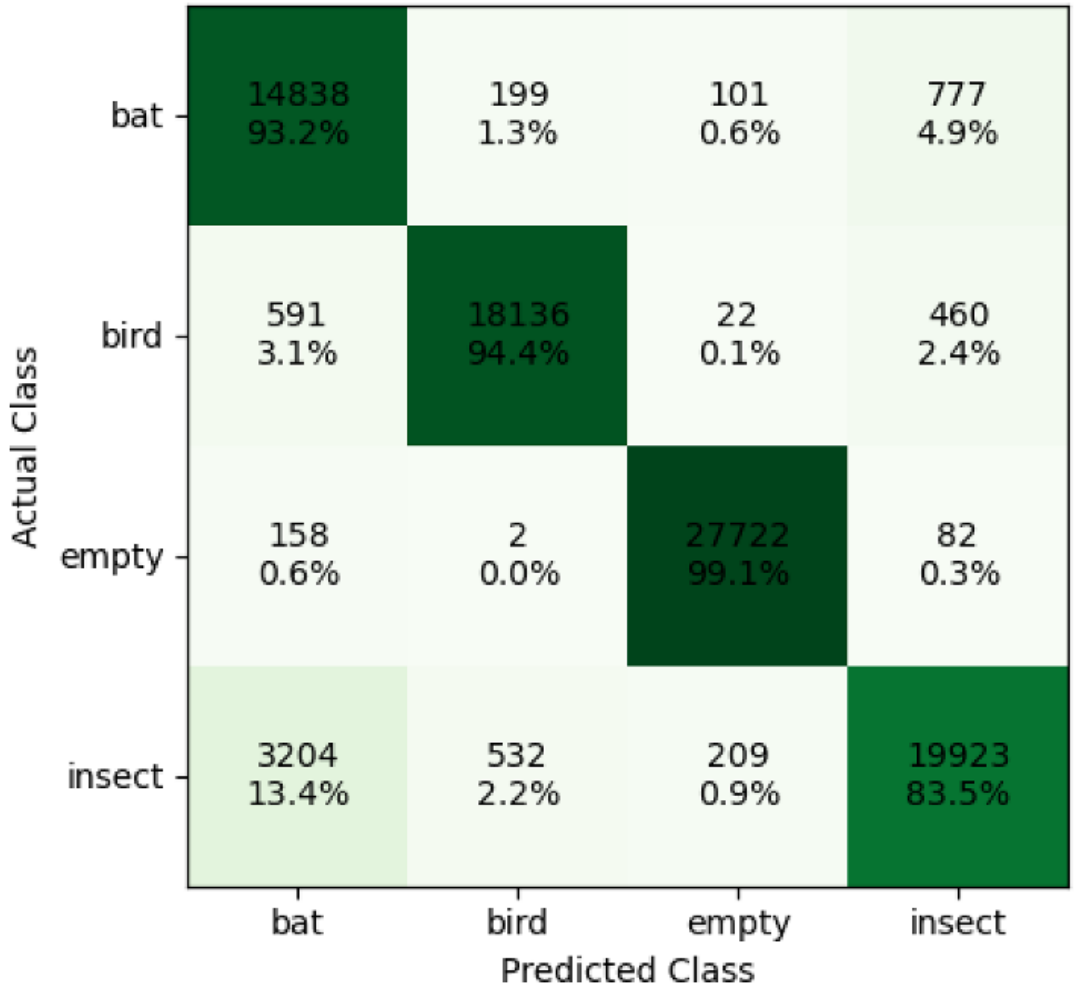
- Experimental set up
  - GPU setting with Skynet from the Bioenergy Science Technology Directorate at NREL
  - NVIDIA RTX3090 with Driver Version 470.57.0, CUDA, cuDNN, TensorFlow library



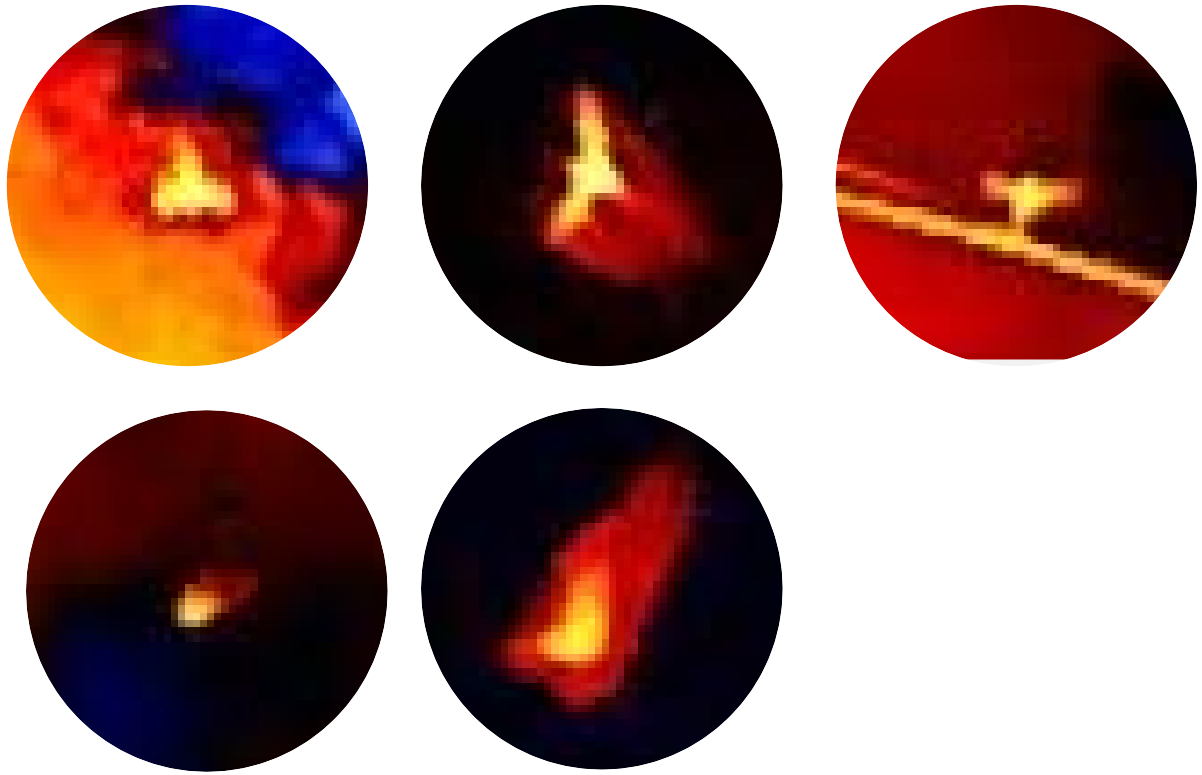
- Dataset
  - **870,033 images** of unified 50x50 size
  - 4 classes – bat (159,045), bird (192,045), insect (238,980), and non-biological object (279,963)

- ML model training with transfer learning
  - Backbone model option:
    - **VGG**, ResNet, Inception, Xception
  - Hyperparameter choices:
    - # of freezing layers, # of classification layers with units, weight initialization, optimizer, learning rate, etc.

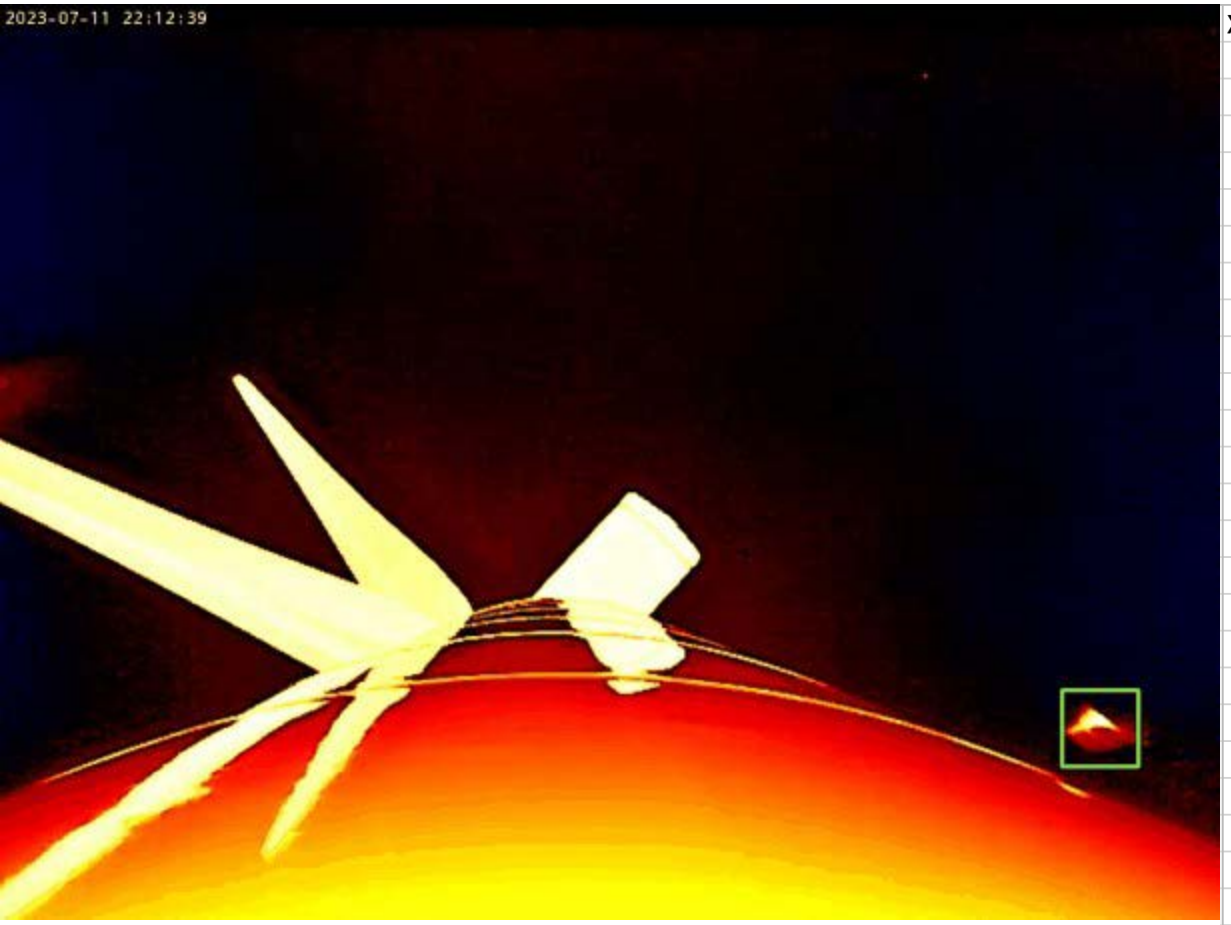
Achieved over 93% accuracy on average for classification



Example of successful detection of real bats



We can now track 2D Bat Flight Trajectory!



X	Y	Width	Height	Object ID	Analysis Date	Analysis Time	Object Name	Current Frame	Probability
747	469	53	53	1	5/20/24	29:03.6	bat	346824	[6.7684746e-
722	460	74	55	1	5/20/24	29:03.8	bat	346825	[1.5576882e-
696	456	58	35	1	5/20/24	29:04.2	bat	346826	[1.8075279e-
684	434	52	47	1	5/20/24	29:04.5	bat	346827	[1.8875493e-
656	428	60	38	1	5/20/24	29:04.8	bat	346828	[7.4401581e-
644	423	60	35	1	5/20/24	29:05.1	bat	346829	[4.6358593e-
620	400	59	47	1	5/20/24	29:05.4	bat	346830	[1.7603651e-
602	391	58	40	1	5/20/24	29:05.6	bat	346831	[1.7397796e-
592	375	60	46	1	5/20/24	29:06.0	bat	346832	[6.2573701e-
582	350	41	53	1	5/20/24	29:06.3	bat	346833	[5.0453889e-
558	343	51	47	1	5/20/24	29:06.6	bat	346834	[4.2875173e-
549	336	45	43	1	5/20/24	29:06.9	bat	346835	[8.0620458e-
534	312	42	52	1	5/20/24	29:07.2	bat	346836	[9.5796722e-
512	295	52	48	1	5/20/24	29:07.6	bat	346837	[4.2756258e-
501	277	61	49	1	5/20/24	29:07.9	bat	346838	[1.8054124e-
490	242	46	69	1	5/20/24	29:08.1	bat	346839	[4.1875333e-
481	216	39	68	1	5/20/24	29:08.3	bat	346840	[3.2587397e-
465	199	47	68	1	5/20/24	29:08.5	bat	346841	[3.5182192e-
453	176	44	61	1	5/20/24	29:08.6	bat	346842	[1.3892368e-
432	156	46	52	1	5/20/24	29:08.7	bat	346843	[6.6471297e-
418	122	52	72	1	5/20/24	29:08.9	bat	346844	[1.1993747e-
405	99	51	75	1	5/20/24	29:09.1	bat	346845	[5.7287194e-
429	141	13	10	1	5/20/24	29:09.2	bat	346846	[3.3714362e-
371	55	45	57	1	5/20/24	29:09.5	bat	346847	[5.5922684e-
354	23	46	73	1	5/20/24	29:09.7	bat	346848	[5.3531672e-

How to expand it into 3D flight trajectories?

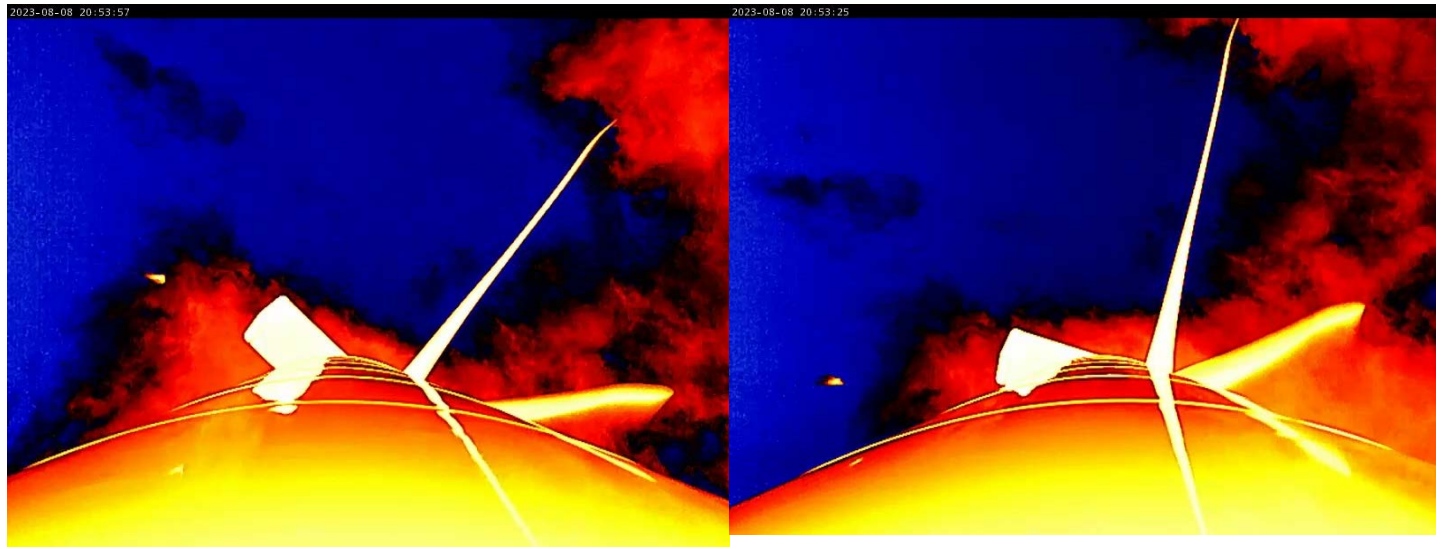
3D Bat Monitoring Methodology using stereo cameras

Left Camera

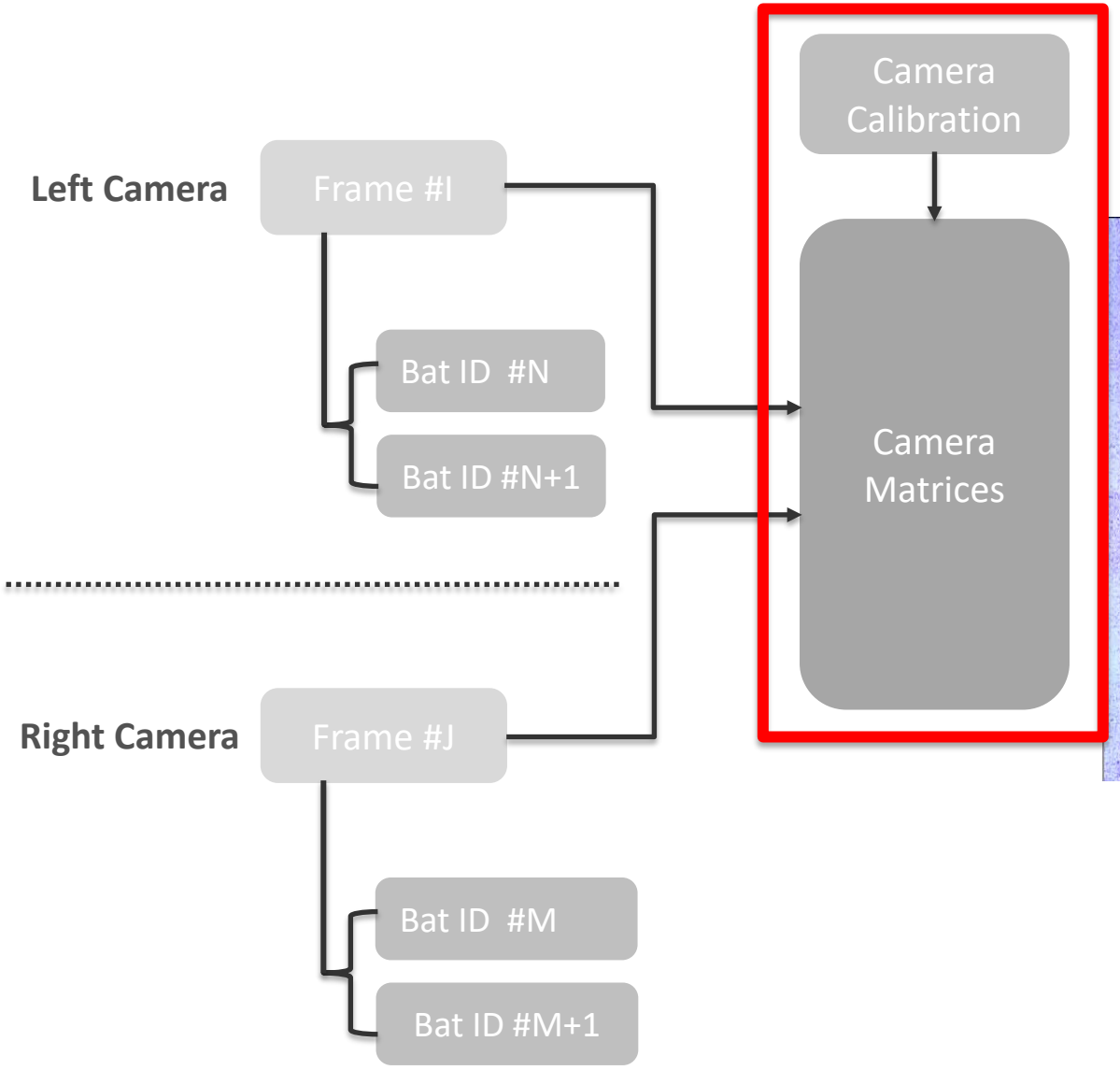
- Frame #I
  - Bat ID #N
  - Bat ID #N+1

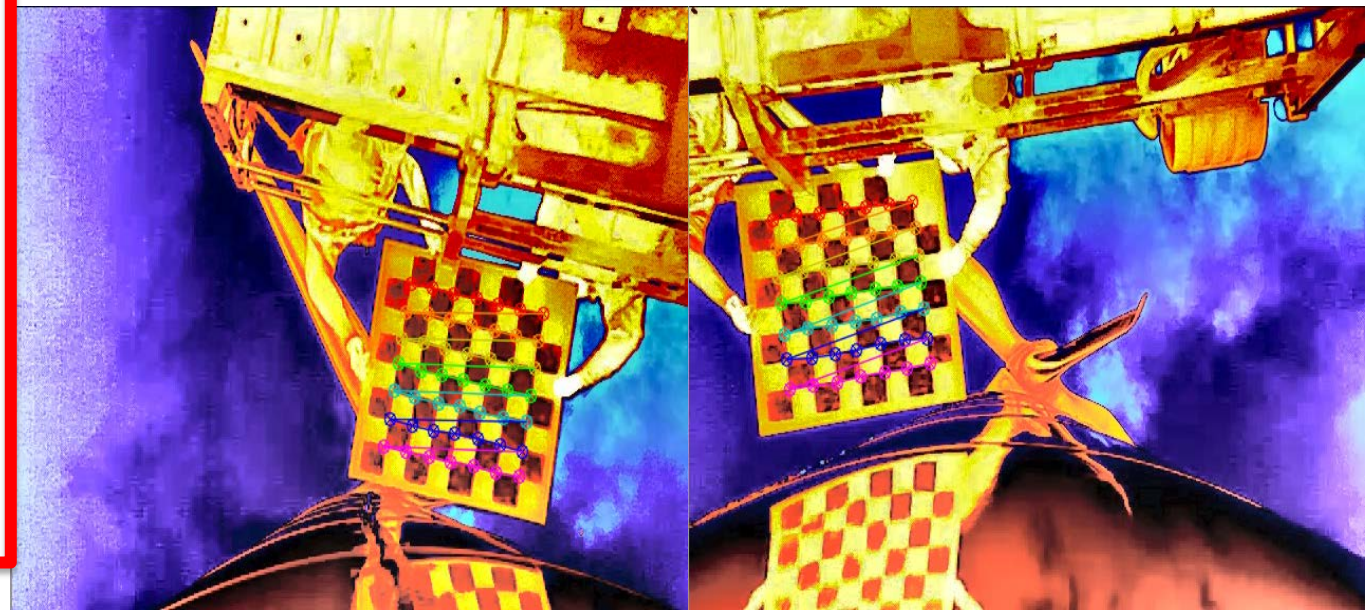
Right Camera

- Frame #J
  - Bat ID #M
  - Bat ID #M+1



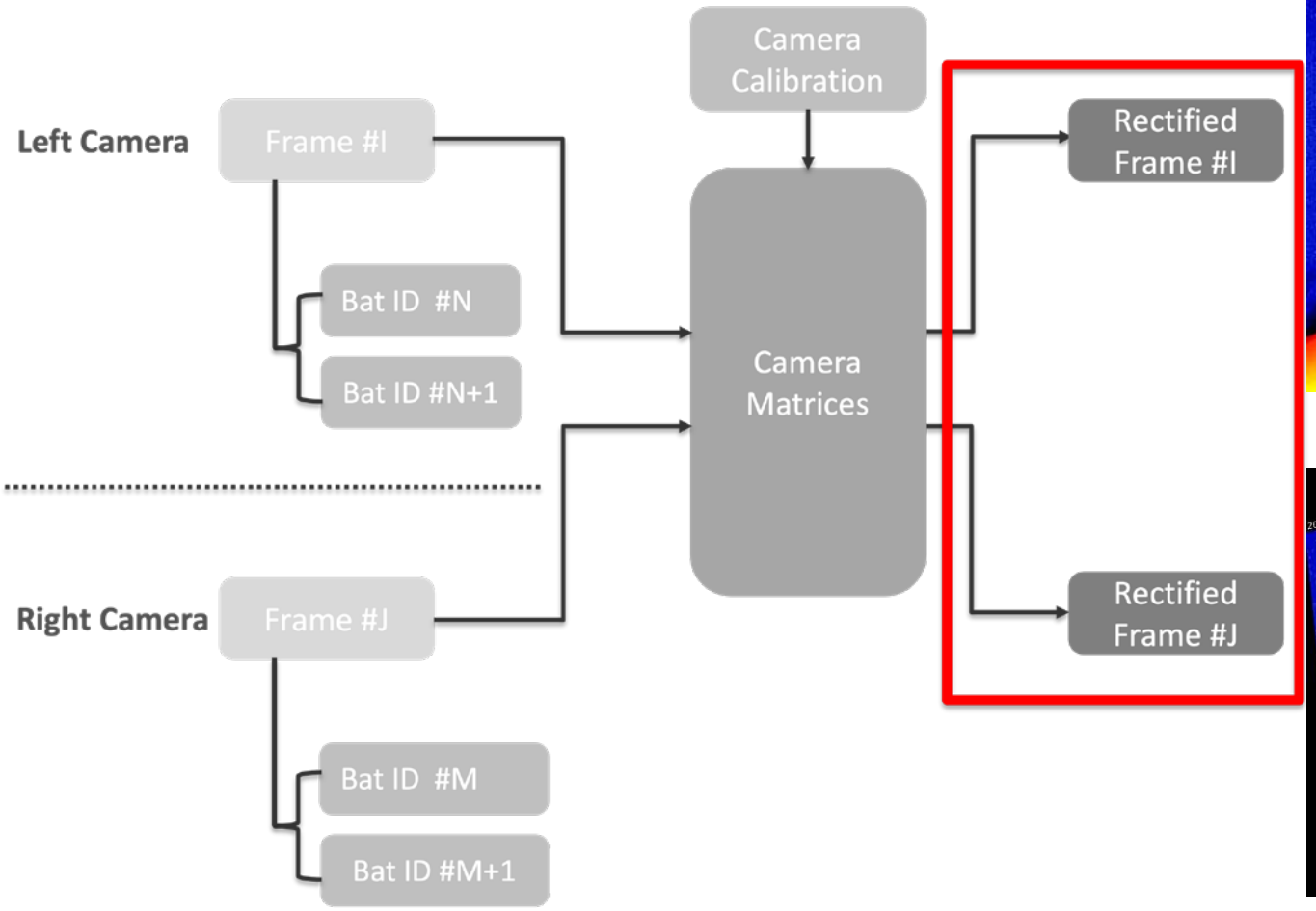
3D Bat Monitoring Methodology using stereo cameras

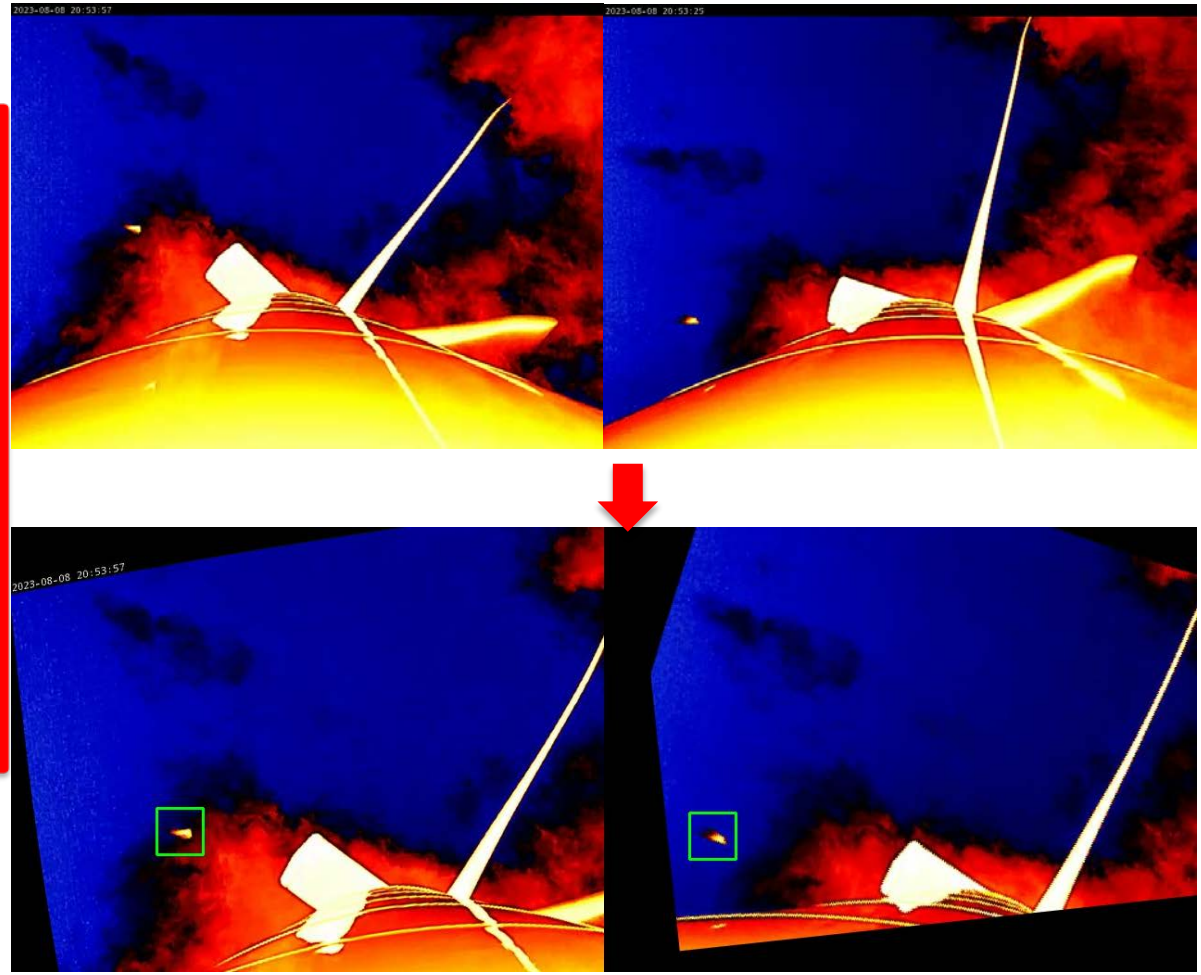




- Camera calibration
  - Obtain matrices for intrinsic distortion, extrinsic rotation, and translation of the camera, which ultimately associates distance to pixel.

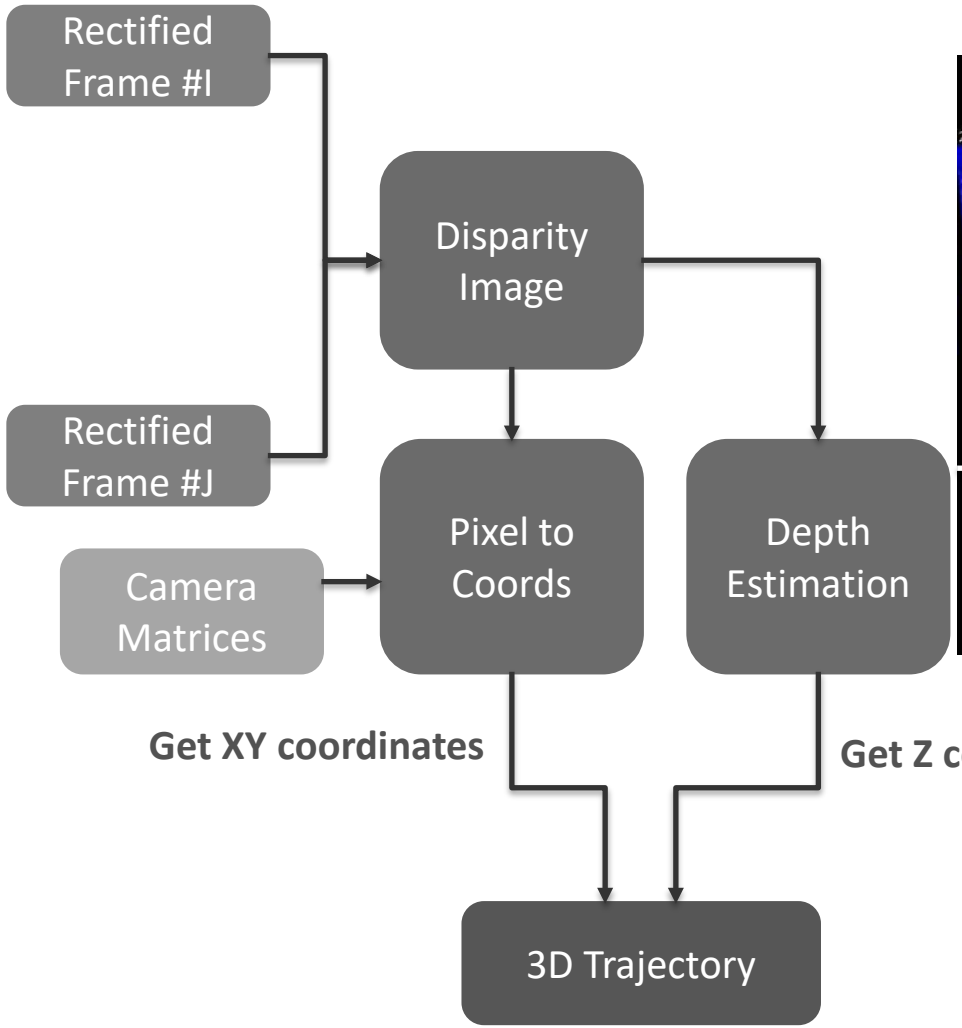
3D Bat Monitoring Methodology using stereo cameras

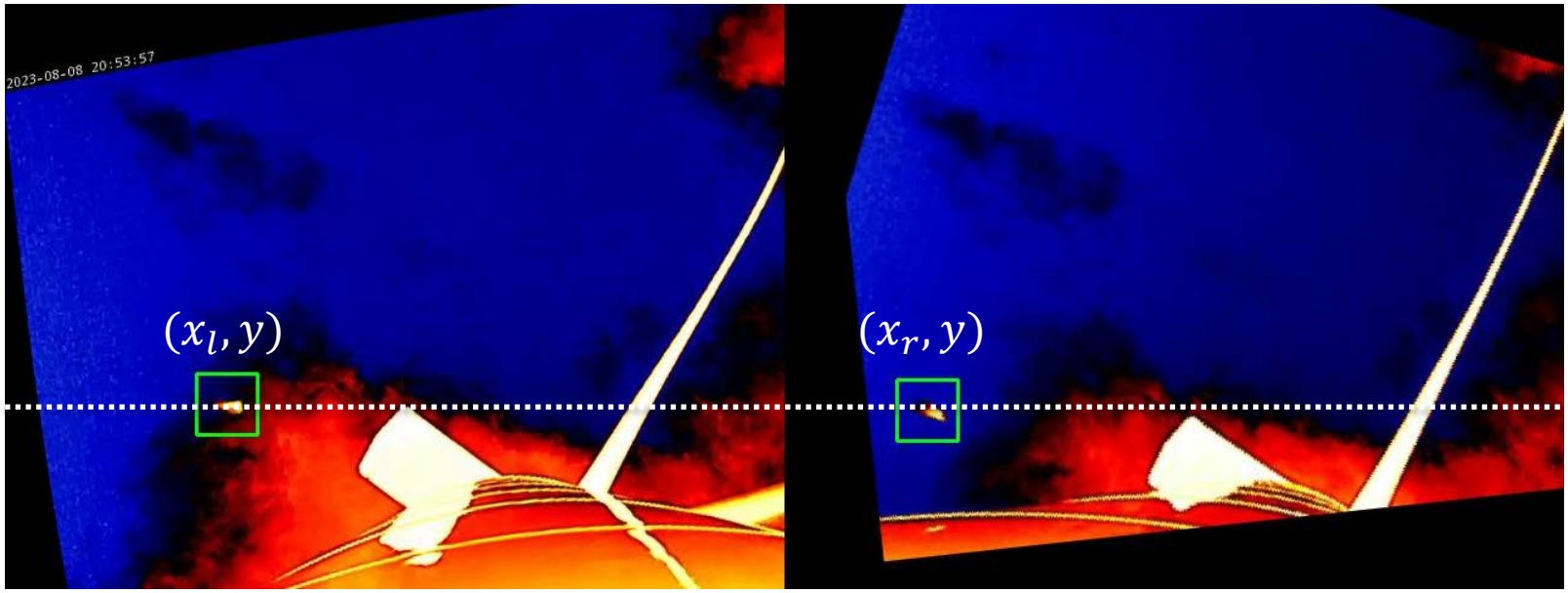




Adjusts both camera image planes to be parallel

3D Bat Monitoring Methodology using stereo cameras





$$\frac{B}{Z} = \frac{B + x_r - x_l}{Z - f}$$

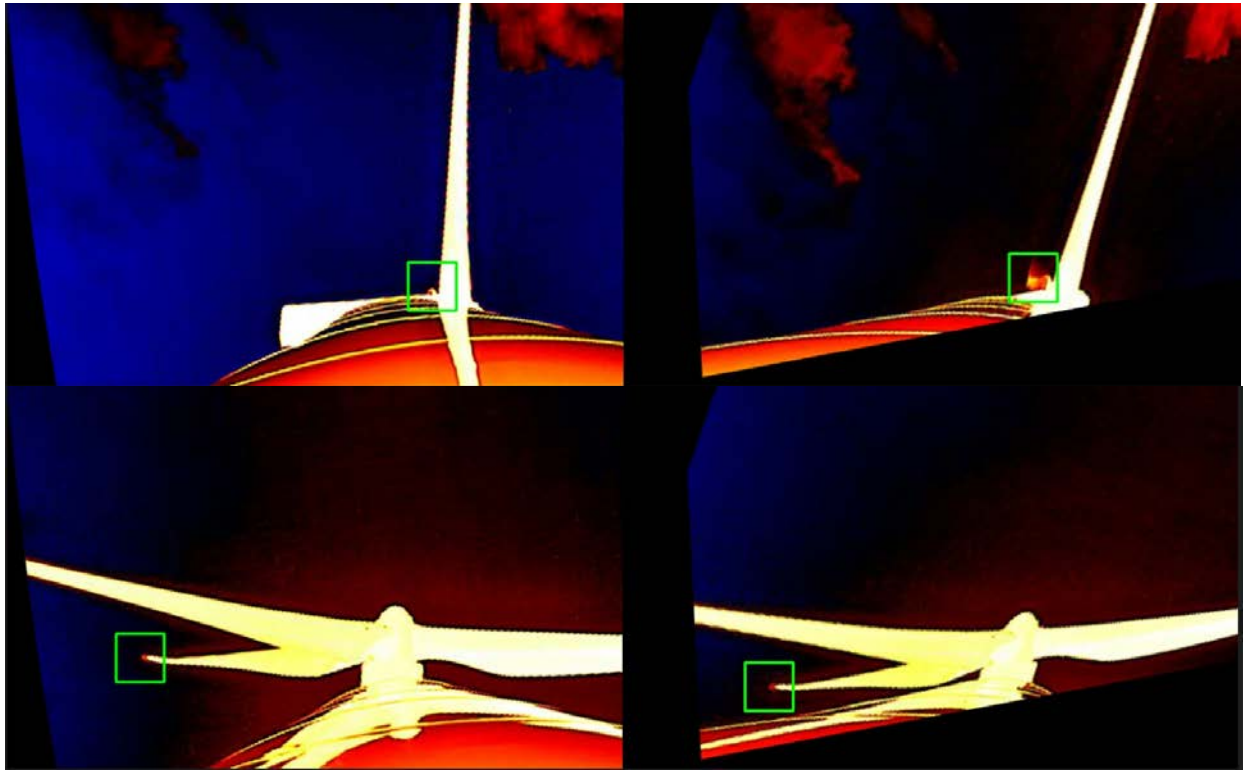
$$Z = \frac{B \cdot f}{x_l - x_r}$$

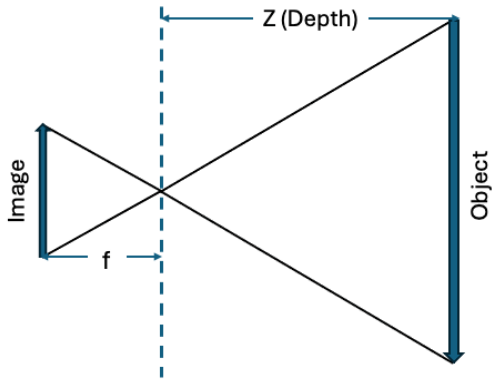
where:

B = the baseline
f = the focal length
$x_l - x_r$ = the disparity

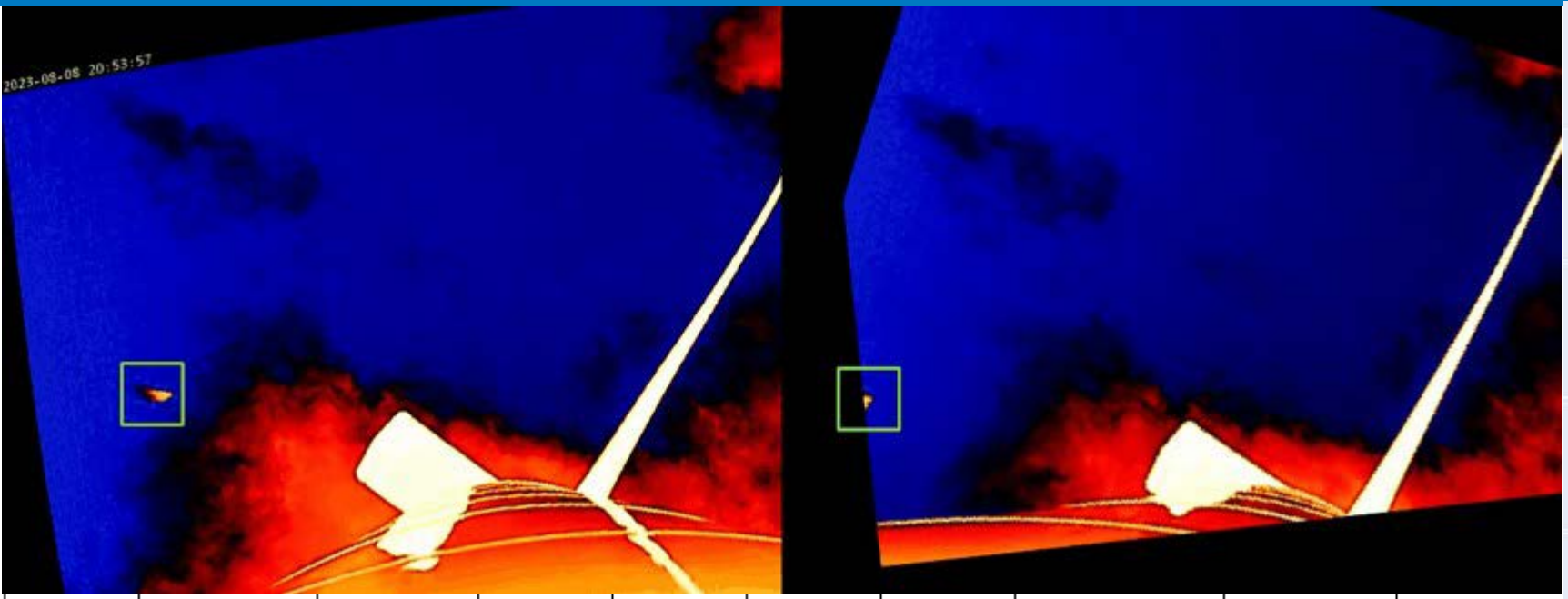
Validation of 3D Bat Flight Trajectories

- Post-processing & Data QC Metrics
  - Cross-reference with SCADA high-freq data
  - Consider expected bat velocity range (12-25mph)
  - Remove false-positives with estimated wingspan and real object size
  - Compare rotating blade tip height range (4053cm – 11430cm)

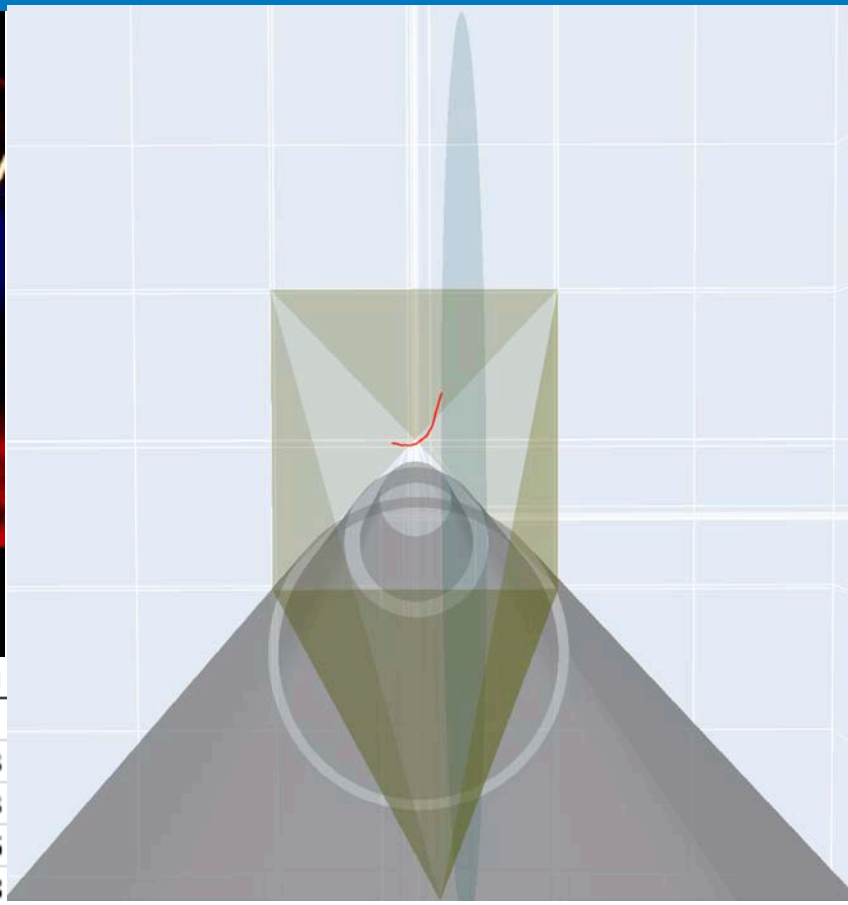




Bat 3D Flight Path Reconstruction



Date	Time	Object Type	ID	X (cm)	Y (cm)	Z (cm)	Distance (cm)	Speed (cm/s)	Speed (mph)
8/8/23	20:52:38.767	bat	282	-102.039	-136.199	3147.524			
8/8/23	20:52:38.800	bat	282	-85.3062	-134.804	3146.019	16.8578438	510.843752	11.4272493
8/8/23	20:52:38.867	bat	282	-60.9044	-127.832	3143.142	25.54073571	381.205011	8.52731323
8/8/23	20:52:38.900	bat	282	-49.0522	-129.227	3139.079	12.6069129	382.027664	8.54571546
8/8/23	20:52:38.967	bat	282	-22.5589	-127.832	3133.988	27.01396465	403.193502	9.01918178
8/8/23	20:52:39.000	bat	282	-14.8898	-132.713	3127.92	10.92925229	331.189463	7.4084973
8/8/23	20:52:39.034	bat	282	-3.73471	-133.41	3120.779	13.26325241	390.095659	8.72619137
8/8/23	20:52:39.200	bat	282	38.0968	-162.692	3112.309	51.75971537	311.805514	6.97489071
8/8/23	20:52:39.234	bat	282	44.37153	-171.058	3102.275	14.49273624	426.256948	9.53509637
8/8/23	20:52:39.300	bat	282	56.22379	-191.974	3090.508	26.7655779	405.539059	9.07165039
8/8/23	20:52:39.367	bat	282	65.28728	-214.981	3077.138	28.1112332	419.570645	9.38552802
8/8/23	20:52:39.400	bat	282	69.47043	-226.834	3062.617	19.20531758	581.979321	13.0185066

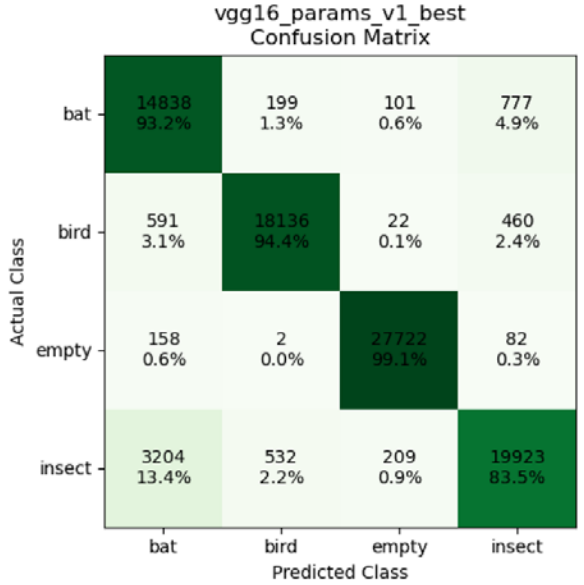


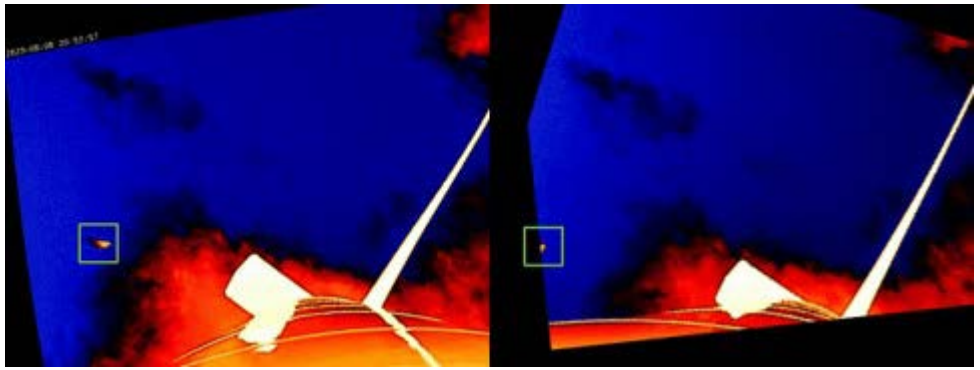
Identified bats (left)
→ reconstructed track (right)

Conclusion

- Moved the research community and industry closer to fully automated wildlife behavioral analysis and real time reporting to help expedite the research

- Cost effective thermal tracking system that
  1) is computationally inexpensive with the ability to run in real time on laptop
  2) can detect and classify animals moving in the field of view with the ability to distinguish between bats (93.2%) , birds (94.4%), insects (83.5%) and non-biological objects (99.1%)
  3) can provide the 3D flight trajectories
  4) can be easily retrained to enhance performance on other types of applications
  5) is entirely open source, allowing it to be accessed, maintained, understood, adapted, and improved upon by a broad range of end users. **(https://github.com/NREL/WEBAT)**





- Future works
  - Expand the monitoring system to include other type of sensors
  - Bat behavioral studies
    - Understand the interaction of bats with wind turbines

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  - Cris Hein
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Thank you!

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