Project Title: Eagle Take Minimization System

Contract: DE-EE0007884.0000

Final Technical Report

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Table of Contents

1. Executive Summary

Laufer Wind (LW) has developed a prototype Eagle Take Minimization System that shows capabilities for autonomously detecting, tracking, and visually identifying eagles and other protected avians out to approximately 1 km range with no human-in-the-loop. This type of detection system is important for animals that fly too close to facilities that can harm them, such as large wind turbine farms. The Eagle Take Minimization System consists of networked and sensor-fused commercial-off-the-shelf (COTS) X-band radars, PZT visible cameras and a Central Controller computer that can be interfaced with a wind facility SCADA. The intended design of the Eagle Take System is to detect and reliably identify eagles at far enough range so that proximate turbines can be stopped to greatly reduce the risk of eagle injury or death. These curtailed turbines would be released when eagles have moved away. Other wind turbines that are not in close proximity to eagles would continue producing electricity as usual throughout the process.

Initial testing demonstrated the ability of LW MD-12 X-band Doppler radar to detect and track eagle-sized targets at ranges greater than 3km. LW used radar tracks to cue Axis cameras towards a target utilizing the cameras' pan and tilt functions. LW successfully integrated the Caffe image classification framework with in-house video tracking software.

Planned testing at wind turbines did not occur during the project period.

2. Project Goals

The Eagle Take Minimization System offers significant technical innovation in avian detection, identification and protection through its use of sensor-fused x-band radars and visible cameras. Project goals were to demonstrate a working prototype Eagle Take Minimization System as follows.

- Use Laufer Wind COTS Doppler radars to initially detect and track airborne targets that have radar signatures similar to eagles.
- Use COTS visible cameras and COTS machine learning algorithms to positively identify targets as eagles (or not).
- Provide commands for turbines OFF, through a SCADA interface, based on the proximity of eagles.
- Provide commands for turbines ON, when eagles move away or are no longer in danger.

Testing and system performance validation were accomplished using drone aircraft as eagle surrogates which resemble live birds.

3. Eagle Take System Functional Block Diagram

Figure 1 shows a functional block diagram of the Eagle Take Minimization System. The system is comprised of two levels of sensor networks (radars and cameras), which are combined with a central controller computer that uses powerful machine learning algorithms to identify avian species, and wind farm SCADA interfacing.

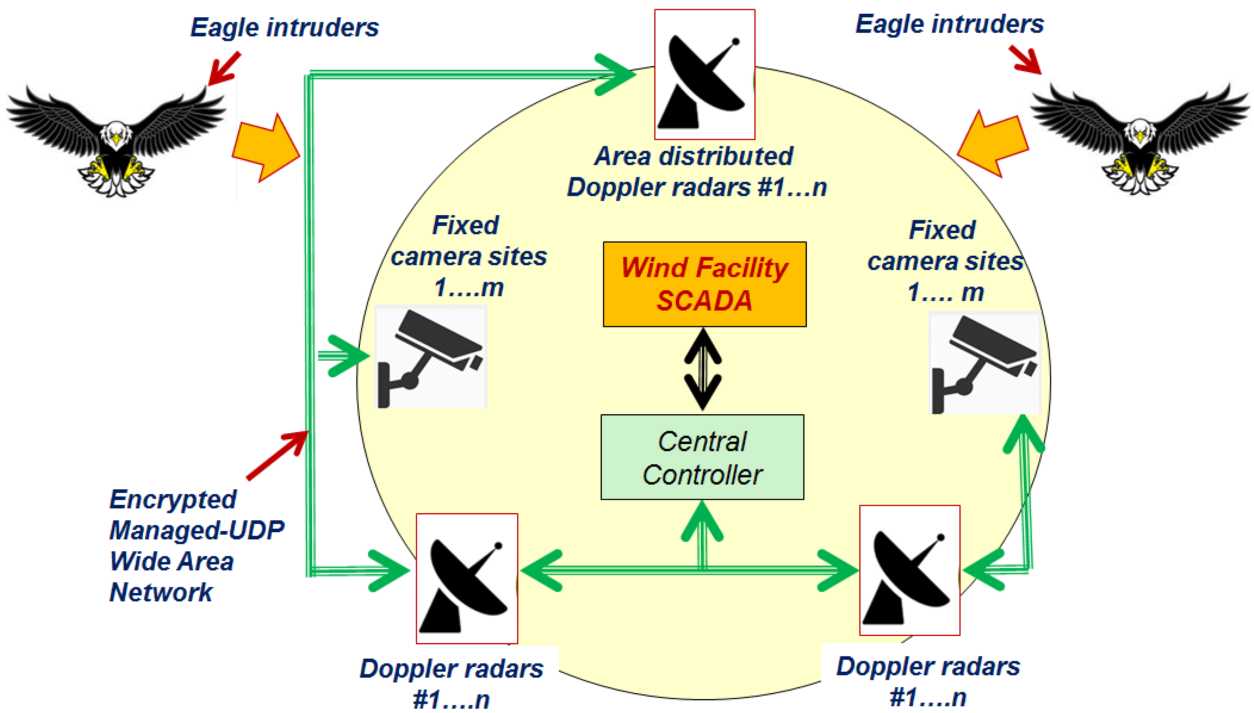


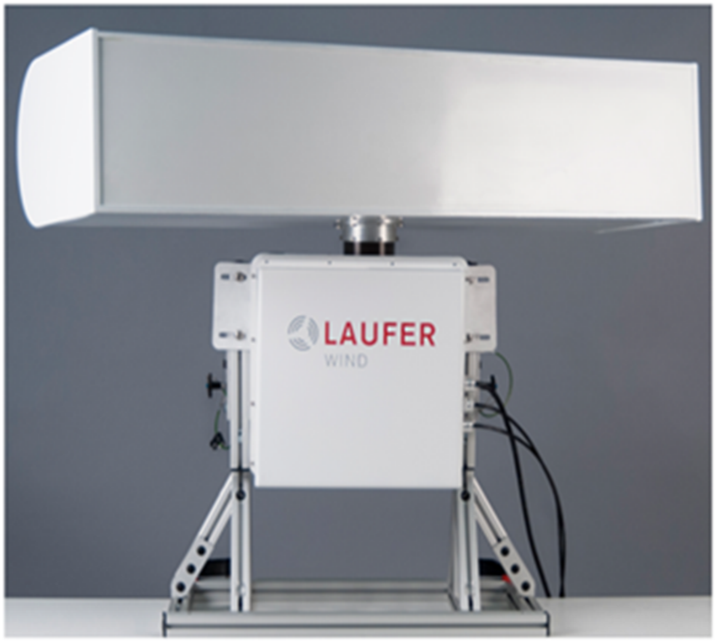
Figure 1. Eagle Take Minimization System functional block diagram.

The subsystems of the Eagle Take Minimization system are as follows:

- A network of Laufer Wind MD-12 X-band Doppler radars (Figure 2), which have a demonstrated ability to detect and track eagle-sized targets at ranges of greater than 3 km.[1] The radars have overlapping fields of view to create a perimeter around the wind farm.

- A network of distributed COTS pan-tilt-zoom (PTZ) cameras, such as the Axis Q6115-E or similar,[2] which are placed around the farm, again with overlapping fields of view. The cameras slew to cues from the radar to point at potential eagle targets for identification.
- A Central Controller computer, which performs the following functions:
  - Fuses tracks from multiple radars
  - Selects camera closest to target and commands that camera towards the target utilizing cameras' pan, tilt and zoom functions.
  - Uses neural net machine learning software and stored image database to classify the target image as an eagle or not with an accuracy approaching 100%. The Central Controller maintains a database of confirmed eagle target imagery, initially created in conjunction with the Southeast Raptor Center at Auburn University, but gradually building its own site-specific image library from identified targets.
  - Connects to the wind farm SCADA network and can command specific turbines to feather (aerodynamic braking), curtailing operation until the eagle moves a safe distance from the hazard, at which time the turbine released to resume operation.

[1] MD-12 Doppler radar description is provided at http://www.lauferradarsystems.com.
[2] http://www.axis.com/us/en/products/axis-q6115-e.

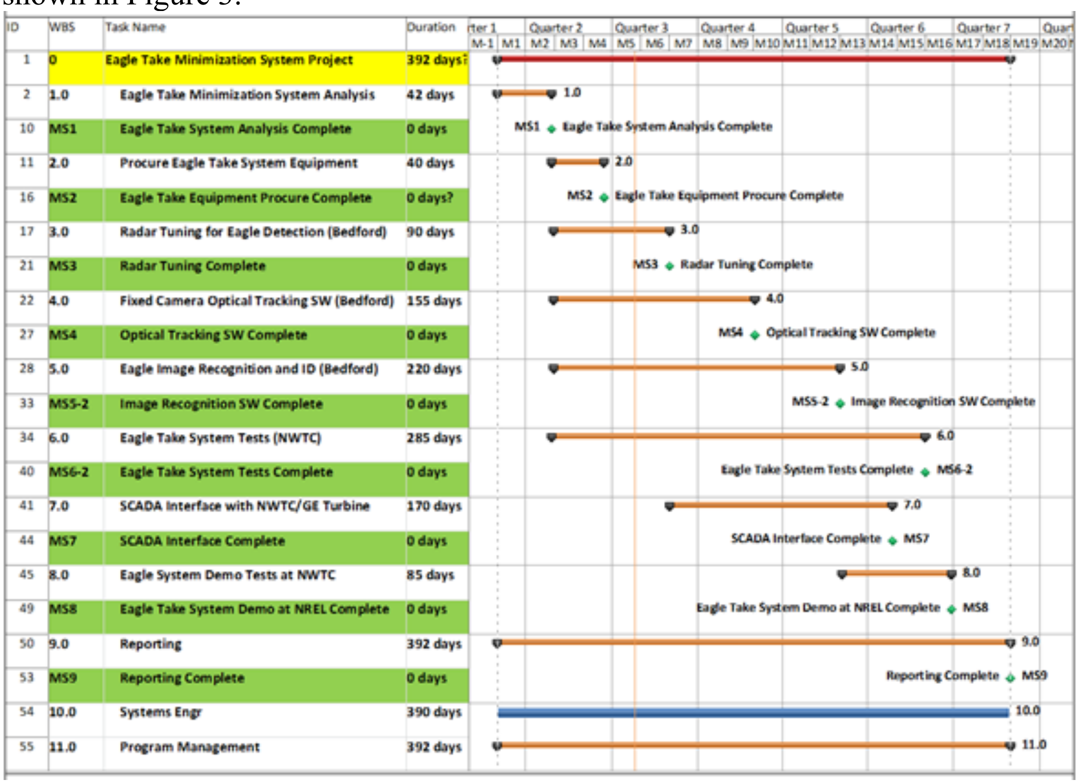


- Detection range: > 12 km for 1 sq-m RCS (all weather)
- Tracking: > 30 simultaneous aircraft
- Frequency: X-band, 9.41 GHz
- Peak rf power: 12 kW
- Average rf power: 12 W
- Rotating antenna: 20 rpm
- Radar package size: ~ 15 in x15 in x20 in
- Antenna package: 12 in x 12 in x 48 in
- Beam pattern: 2 by 11 degrees
- Radar weight: 103 lbs with antenna
- Power: 115/230VAC, 50/60Hz, 200W
- Temp range: -40 degC to + 55 degC
- Environmental: IP56
- Safety: ETL and CE approved
- EMC: FCC approved
- Reliability: > 6.5 years (MTBR)

Figure 2. Commercial MD-12 pulse Doppler radar.

4. Project Work Breakdown Structure (WBS)

Laufer Wind identified a project WBS for the Eagle Take Minimization project that consisted of 10 technical tasks and an 18 month milestone schedule. The WBS task and milestone schedule is shown in Figure 3.



ID	WBS	Task Name	Duration
1	0	Eagle Take Minimization System Project	392 days?
2	1.0	Eagle Take Minimization System Analysis	42 days
10	MS1	Eagle Take System Analysis Complete	0 days
11	2.0	Procure Eagle Take System Equipment	40 days
16	MS2	Eagle Take Equipment Procure Complete	0 days?
17	3.0	Radar Tuning for Eagle Detection (Bedford)	90 days
21	MS3	Radar Tuning Complete	0 days
22	4.0	Fixed Camera Optical Tracking SW (Bedford)	155 days
27	MS4	Optical Tracking SW Complete	0 days
28	5.0	Eagle Image Recognition and ID (Bedford)	220 days
33	MS5-2	Image Recognition SW Complete	0 days
34	6.0	Eagle Take System Tests (NWTC)	285 days
40	MS6-2	Eagle Take System Tests Complete	0 days
41	7.0	SCADA Interface with NWTC/GE Turbine	170 days
44	MS7	SCADA Interface Complete	0 days
45	8.0	Eagle System Demo Tests at NWTC	85 days
49	MS8	Eagle Take System Demo at NREL Complete	0 days
50	9.0	Reporting	392 days
53	MS9	Reporting Complete	0 days
54	10.0	Systems Engr	390 days
55	11.0	Program Management	392 days

Figure 3. Eagle Take Minimization Project WBS and Milestone schedule.

The WBS technical tasks consisted of the following.

- **Task 1.0 System Analysis.** LW performed overall Eagle Take Mitigation System design and analysis for radars, Central Controller, fixed and cameras, and network communications. Analyses identified specific COTS components to meet Eagle Take system requirements.
- **Task 2.0 Procure Equipment.** LW set up an MD-12 Doppler radar system, and procured two camera systems and the required network equipment.
- **Task 3.0 Radar Tuning for Eagle Detection.** LW tuned the MD-12 Doppler radar for detecting birds and eagle drone targets.
- **Task 4.0 Fixed Camera Optical Tracking.** LW developed and integrated camera auto-track software with the Radar and Central Controller. Camera auto tracking and image recognition were successfully evaluated using Eagle UAV surrogates.
- **Task 5.0 Eagle Image Recognition and ID.** Laufer Wind integrated COTS image recognition software with the Central Controller for unambiguous eagle identification. Eagle recognition and identification were evaluated with eagle UAV surrogates.
- **Task 6.0 Eagle Take System Tests (NWTC), Task 7.0 SCADA Interface with NWTC/GE Turbine,** and **Task 8.0 Eagle Take Demo Tests at NWTC** were not completed.
- **Task 9.0 Reporting**, **Task 10.0 System Engineering**, and **Task 11.0 Program Management** were maintained for the duration of the project.

4. Project Technical Discussion

The following narrative describes technical progress and measurements in each of the Eagle Take Minimization System tasks.

Task 1: Systems Analysis

System analyses used a Quality Function Deployment process to assess the relative importance and impact of stakeholder values on an Eagle Take Mitigation System design. Stakeholders include DOE, US Fish and Wildlife Service, and wind farm developers and operators. These values were used to generate a set of customer requirements which were further refined into functional, performance, and constraint requirements for the Eagle Take Minimization System. Requirements identified as Key Performance Parameters (KPPs) are those metrics that define Eagle Take System performance. These metrics include probability of detection of eagle-sized targets, probability of establishing a track on said targets, probability of visual detection, and probability of species identification. Figure 4 presents a chart summary of project KPPs that define radar probability of detection and track, camera probability of detection and identification, and turbine curtailment range for eagle targets.

- Radar Probability of Detection (PD) (eagle targets):
  - PD > 0.7 at range < 2 km in clear weather
  - PD > 0.5 at range > 2 to 4 km in clear weather
- Autonomous Operation
  - In normal use, the system shall be capable of unattended and autonomous operation
- Radar Probability of False Alarm (PFA)
  - PFA < 1e-5 in clear weather.
  - False alarms shall not include targets that are not eagles, such as other birds, aircraft, or fluctuating clutter background.
- Radar Probability of Track (PoT)
  - Track defined as association of two or more detections
  - PoT > 0.8 at range < 2 km
  - PoT > 0.6 at range > 2 to 4 km
- Probability of Visual Detection (PVD)
  - PVD > 0.8 at ranges less than 2 km in clear weather
- Probability of Visual Identification (PVI)
  - PVI > 0.8 at range < 1 km in clear weather
- Curtailment Range
  - Alarm sent to the site SCADA when eagle target is < 500 m from a turbine

Figure 4. Summary of key performance parameters (KPPs) for the Eagle Take Minimization project.

A flow-down of the system requirements to hardware performance requirements led to the down-select of acceptable hardware for the Central Controller computer, the pulsed Doppler radar, camera subsystems, and the selection of software packages for image recognition and classification.

Task 2: Equipment Procurement

MD-12 Pulsed Doppler Radar

Laufer Wind produced a commercial MD-12 pulsed Doppler X-band radar that was used in its Aircraft Detection System.[3] Systems analyses and actual eagle detection measurements at NREL Wind Technology Center in February 2016 showed the MD-12 was an excellent platform to detect and track eagles and other raptors out to ranges exceeding 3 km in all weather.[4] Figure 5 shows a photograph of two MD-12 radars mounted on a man-lift that was dedicated to use on this project at LW's Bedford NH engineering facility.

3 http://www.lauferradarsystems.com/ and http://www.lauferwind.com/.

4 Eagle detection and track was discussed in Laufer Wind technical proposal to the DOE, Project Title: Eagle Take Minimization System, FOA Topic Area: DE-FOA-0001554, September 13, 2016.

Figure 5. Photograph of MD-12 Doppler radars being used on the Eagle Take project.

Visible Tracking Cameras

Optical analyses were coupled with test images using a pre-trained BAIR Caffe[5] image recognition model to determine the minimum range resolution and field of view required to resolve and classify raptor-type target sets to a range of 1 km. For a bird with a 2 m wingspan, this was determined to be a resolution of 100 pixels across, or 2 cm per pixel, before the classifier began to present errors in its determination of species. This translates to an instantaneous field of view of 0.4 milliradians which defines the required ratio of sensor element to lens focal length. The Axis Q6115-E [2] with a 1/3" CMOS sensor, 1920x1080 sensor array, and 132mm focal length meets project optical requirements at a very competitive price, and was selected for the Eagle Take Minimization system. Two Q6115-E cameras shown in Figure 6 have been procured by LW as part of its cost-share effort and were networked and integrated with radars at Bedford, NH.

Figure 6. Photograph of two Axis A6115-E surveillance cameras that are used for tracking airborne targets.

[5] http://caffe.berkeleyvision.org/.

Image Recognition Software

Three software packages were evaluated for image processing and classification, these being OpenCV,[6] Google TensorFlow,[7] and BAIR Caffe.[5] A combination of OpenCV and Caffe was selected because (1) pre-trained Caffe models exist which will greatly reduce the development time for the image classification task, and (2) Caffe integrates easily with OpenCV for preliminary image processing tasks (i.e. isolating the target from the background image).

Representative video imagery of birds was used in timing tests of the software package to determine single board computer hardware processing requirements. The computer is required to perform motion detection/background segmentation and image classification within a 3 second refresh rate of radar tracks. LW measurements show an ADLQ170HDS single board computer[8] can perform the image classification at a 10 Hz rate, fast enough that 1 out of every 3 frames may be analyzed. OpenCV and Caffe were used on the prototype Eagle Take System developed by LW at its Bedford NH facility.

Task 3: Radar Tuning for Eagle Detection

Track Association and Filter Tuning

Radar tuning parameters developed by LW on prior work with eagles were installed on an MD-12 radar. The radar that was tuned for eagle tracking had several layers of filters, including geography, velocity, signal intensity, and flight characteristic, which helped discriminate bird tracks from other targets in view.

Radar tracking measurements were made with wild birds flying around Bedford NH. Figure 7 shows radar tracks on small birds (hawk or tern-size and smaller) flying ~ 500 meters down range. The radar filters for tracking birds include reducing minimum target velocity to 5 m/sec and reducing STC (sensitivity time control) to 50 meters. Similar tuning parameters proved effective in tracking live eagles at NREL in February 2016.

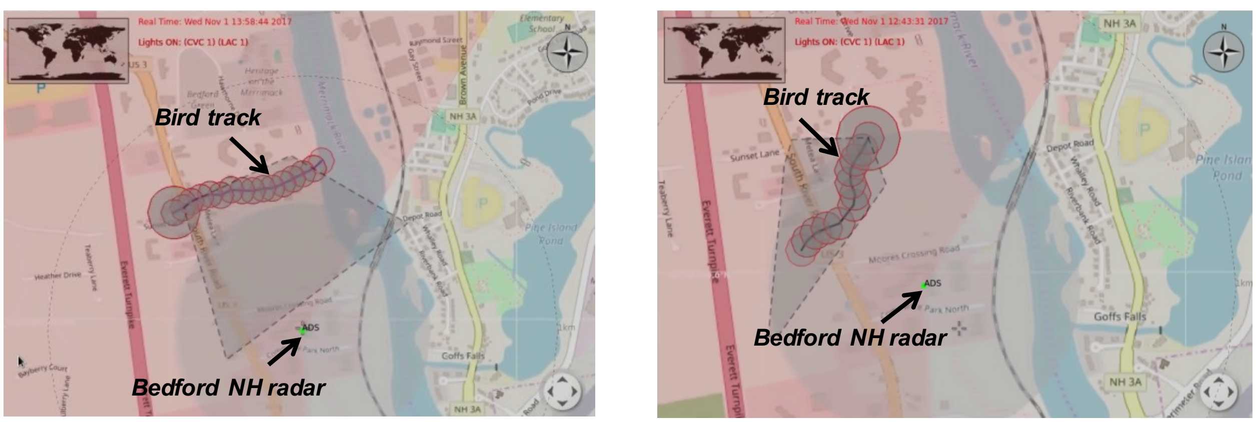


Figure 7. Two examples of MD-12 radar tracking small birds near Bedford NH. Nominal range is 500 meters.

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[6] http://opencv.org/.
[7] https://www.tensorflow.org/.
[8] http://www.adl-usa.com/product/adlq170hds/ with NVIDIA GTX 550Ti and Intel 6th Generation i7 with 8 threads.

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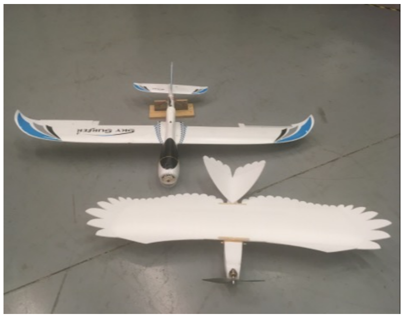
Eagle UAV Target Surrogates

Several eagle surrogate drones were procured and built up with identical electronics packages for flight control and telemetry. Figure 8 shows photographs of fixed-wing drone airframes that were flown near the Bedford, NH facility. LW had secured in-house FAA remote pilot certification to comply with part 107 UAS regulations.



Operational Eagle surrogate drones at Bedford NH

Automated Landing in Bedford ~ 7m Precision

Planned Eagle Paint Scheme

Figure 8. Photographs of surrogate-eagle drone targets being flown and tested at Bedford NH.

Eagle Surrogate RCS Measurement Tests

A set of tests were performed to directly measure the radar cross section (RCS) of the drone airframes that were used to test and evaluate radar and optical trackers. It is important that the surrogate drones have an RCS which is representative of live eagles. Live eagle RCS measurements were taken by LW radars during our prior testing in Colorado, and eagle RCSs were determined to vary in the range of 0.03 to 0.3 square meters, depending on aspect. A good representative RCS for an eagle is 0.15 sq-m.

Eagle targets (Figure 9a) RCS were measured using a weather balloon (Figure 9b) fitted with a one square meter calibrated radar reflector, and flown to a height of 143 m above the height of the radar, which was mounted at 90 degrees to its normal orientation, allowing it to radiate straight up (Figure 9c). After recording returns from the calibrated target, the surrogate target, an alternate UAV, and the surrogate with reflective material added to the wings were suspended from the balloon and radar returns were recorded from them at the same altitude.

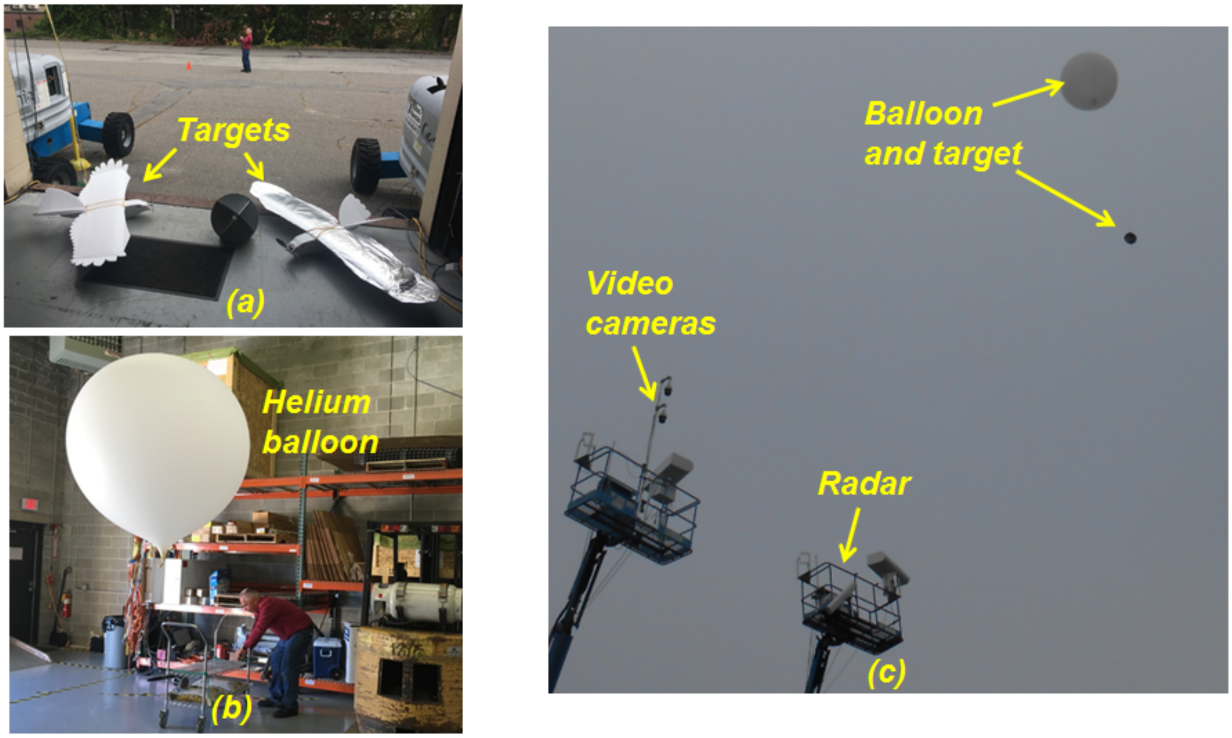


Figure 9. Photographs of (a) two eagle surrogate drones, (b) helium-filled weather balloon used to raise targets above radars for RCS measurements, and (c) Radar Cross-Section measurements on targets tethered to the weather balloon.

Table 1 summarizes RCS measurements for the various targets. The foam body of an eagle surrogate target does not provide as large a target as a live eagle. Adding metal foil brought the RCS up above the target RCS (0.1 sq-m) making the drone surrogate a representative target in both the visual and radar detection domains.

Table 1. Summary of RCS measurements of eagle surrogate targets and hoist balloon.

Target	Peak S/N	Estimated RCS (sq-m)
Calibrated radar reflector	46.4	1.000
Eagle UAV (foam body with aluminum foil)	38.3	0.154
Shark UAV (foam body only)	33.9	0.056
Eagle UAV (foam body only)	33.1	0.047
Balloon	29.6	0.021
Background noise at 140 m	27.2	0.012

Quad-copter Eagle Surrogate Tug

LW found that the fixed-wing drones were difficult to fly and test in harsh New England winters due to prevailing high winds and extremely cold temperatures. LW then developed a drone "tug" configuration using a DJI Phantom quad-copter airframe that dragged eagle balloon silhouettes behind, as shown in Figure 10. The DJI Phantom was robust enough to reliably pull eagle silhouette balloon at the required altitude, range, and speed to simulate eagle flight. The quad-copter had metal foils added to match eagle RCS of ~ 0.15 sq-m. The eagle balloon silhouette is approximately the same size and color as small eagles.

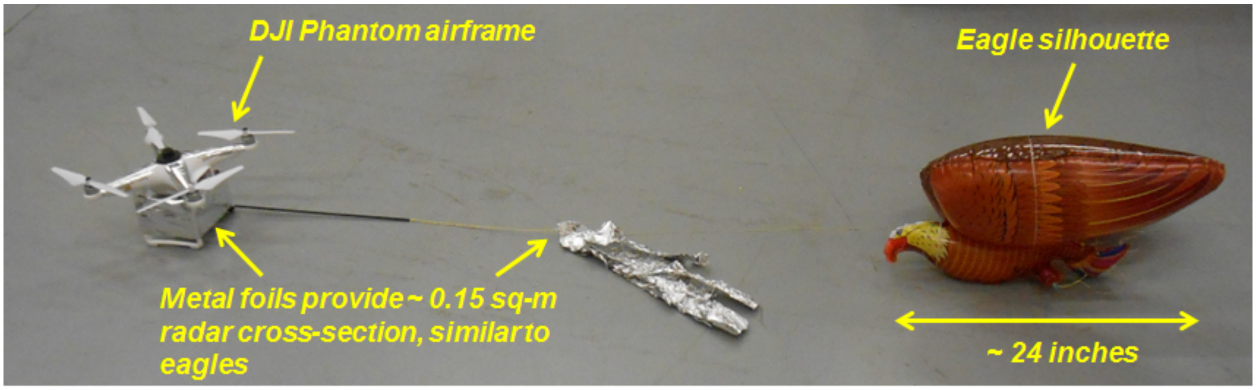


Figure 10. Photograph of DJI Phantom drone that dragged an eagle balloon

Task4: Fixed Cameral Optical Tracking

Two Camera and Radar Tracking Configuration

Real-time measurements on Axis Q115-E surveillance camera pan, tilt, and optical zoom time-response showed that its zoom response was too slow to track relatively fast-moving eagles (up to ~ 30 mph). LW then developed a two camera architecture where one camera operates at ½ zoom (15x magnification) for coarse target optical identification and track, and a second camera is fixed at full zoom (30x) for target recognition and identification. This dual-camera fixed-magnification approach has improved system response time significantly that will allow the system to track very fast-moving eagles (> 40 mph).

The dual-camera eagle tracking system works as follows: the Doppler radar first detects and tracks bird targets of interest. The radar hands off target range and azimuth coordinates (no elevation data as the radar is 2-D) to the ½ zoom camera that establishes a target fix and track in azimuth and elevation. The ½ zoom camera hands off its azimuth and elevation coordinates to the full-zoom camera that performs final target identification and recognition. Figure 11 shows pictures of the two-camera and radar system, along with real-time optical track video imagery of a Cessna aircraft flying approximately 8 km from the radar. The fixed-magnification cameras were cued to the Cessna by the Doppler radar.

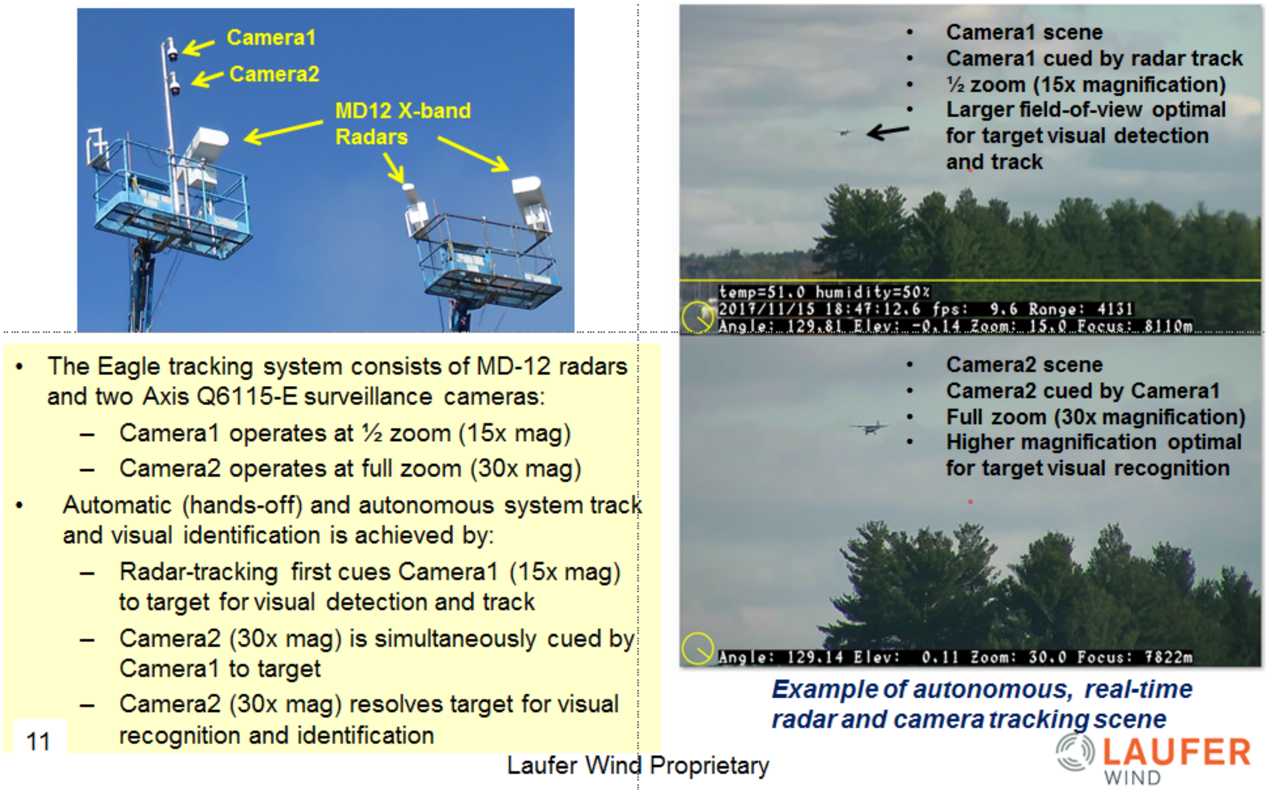


Figure 11. Quad-chart summarizing the fixed-magnification dual camera tracking system and showing examples of autonomous real-time radar and camera tracking scenes.

Surveillance Camera Validation

The surveillance camera system has a requirement to detect, track, and recognize eagles at a minimum range of approximately 500 m. Camera resolution capabilities as a function of target size, weather conditions, and camera magnification were calculated as follows.

- The Johnson Criteria was used to define a target signal-to-noise ratio (SNR) for a median probability of detection (Pd = 0.5).[9]
- CCD array target detection and recognition limits (i.e. SNR) are expressed in terms of [illuminated pixels/min target size]. Target Recognition typically requires 2x-4x more illuminated pixels than Target Detection. [10]
- A conservative Swerling 1 target model maps SNR to Pd and probability of false alarm (Pfa).[11]
- Video range degradation due to atmospheric conditions can be nominally approximated knowing air temperature and relative humidity.[12]

[9] See for example T. Sjaardema et. al. "History and Evolution of Johnson Criteria", Sandia Report SAND2015-6368, 2015.
[10] R. Bailey et. al. "Conceptual Design Standards for eXternal Visibility System (XVS) Sensor and Display Resolution", NASA/TM–2012-217340, 2012.
[11] M. Richards, Fundamentals of Radar Signal Processing, McGraw-Hill, New York, 2005.
[12] See for example Handbook of Optics, Vol 1, Chapter 44:Atmospheric Optics, McGraw-Hill, New York, 1978.

Using these parameters and the Axis camera specifications, it is possible to calculate the Axis camera video range versus target minimum feature size as a function of Detection and Recognition signal strength, and Pd and Pfa requirements. Figure 12 plots Axis Camera video detection and resolution ranges (in km) versus minimum target feature size (in meters) for eagles (0.5 m min feature size), and Cessna (2.5 m min size) and Embraer ERJ-145 (6.5 m min size) aircraft for clear weather and Pd = 0.9 and Pfa = 1 e-5. The predicted eagle recognition range for the camera system is 1 km at full zoom. This camera model calculation meets the KPP requirements listed in Table 1 earlier.

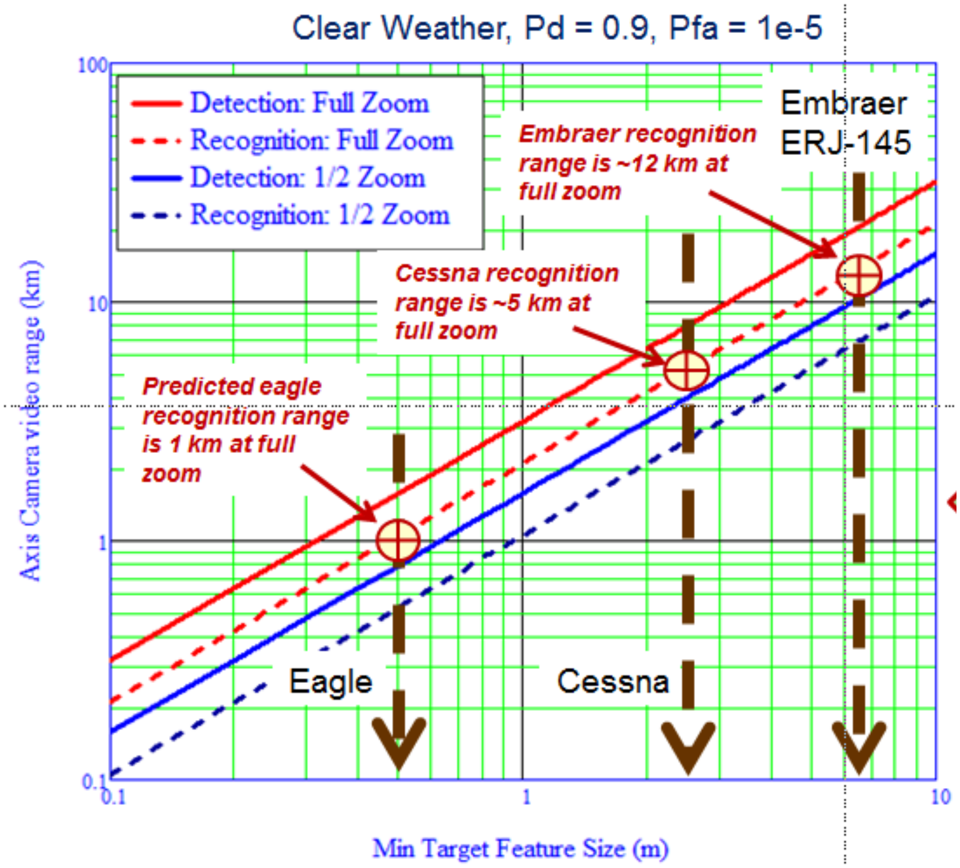


Figure 12. Calculated Axis Camera video range versus minimum target feature size in clear weather for Pd = 0.9 and Pfa = 1e-5. The full-zoom Axis camera can recognize eagles at 1 km distance, and can detect and track eagles to farther range.

We have used commercial aircraft traffic flying near Bedford to validate the Axis camera model. Figure 13 shows imagery from the dual-camera/radar system tracking and recognizing a Cessna airplane (2.5 m minimum feature size) in real-time. The radar cued the ½ zoom camera to the Cessna, and the full-zoom camera adequately resolved the image so that the Caffe Recognition Software successfully recognized and identified the target as an airplane. The camera model predicted the visual range for the Cessna to be 3.7 km at ½ zoom and 4.5 km at full zoom under 10 degC and 51% relative humidity weather conditions. The radar measured the aircraft range to be 4.1 km, which validated the camera model prediction.

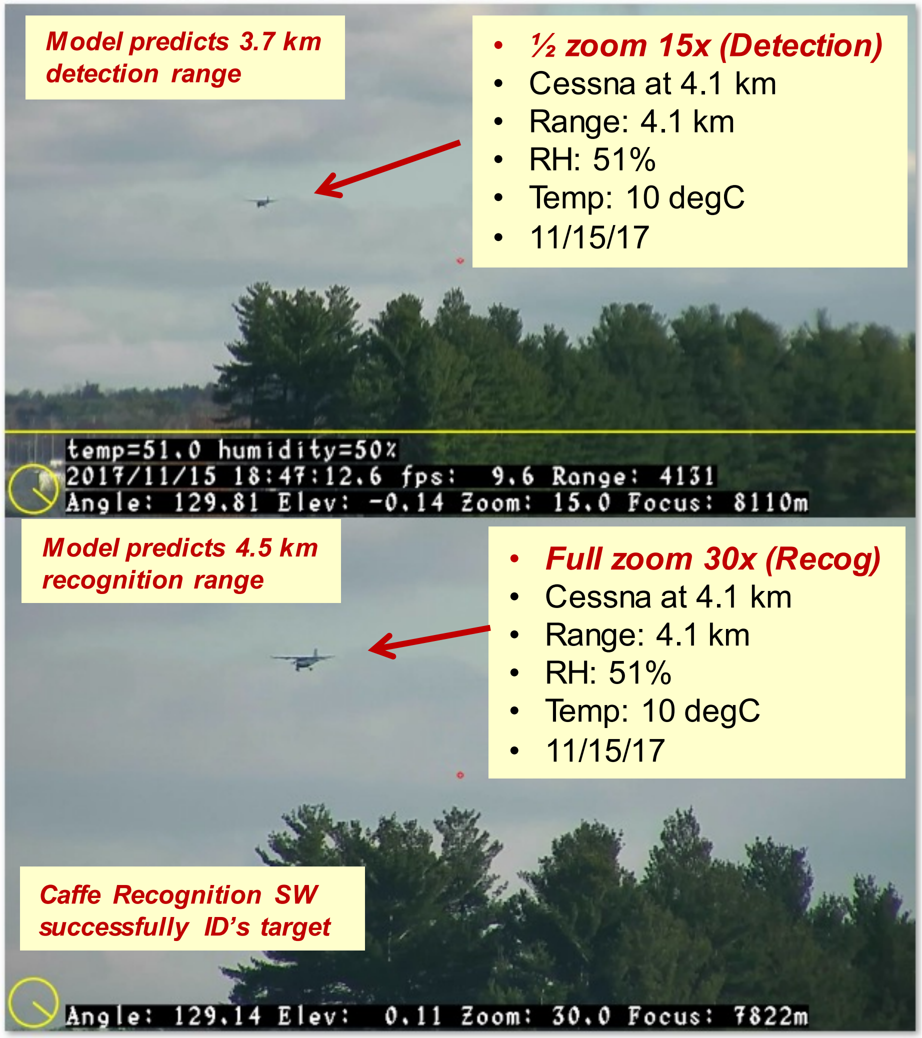


Figure 13. Imagery showing the dual camera/radar tracking system can detect, track and recognize targets in real-time at predicted range.

Figure 14 shows real-time tracking system imagery for a larger Embraer ERJ-145 twin-jet (6.7 m minimum feature size) and a Boeing 373 jet (10 m minimum feature size), both flying away from the radar at a range of ~ 10.1 km. The Caffe Recognition software correctly identified both targets as jet airplanes. The camera model predicted the Embraer detection range to be 9.4 km with a recognition range of 11.5 km. The model predicted Boeing 737 detection to be 10.2 km and a recognition range of 12.9 km. These measurements also validate the camera model.

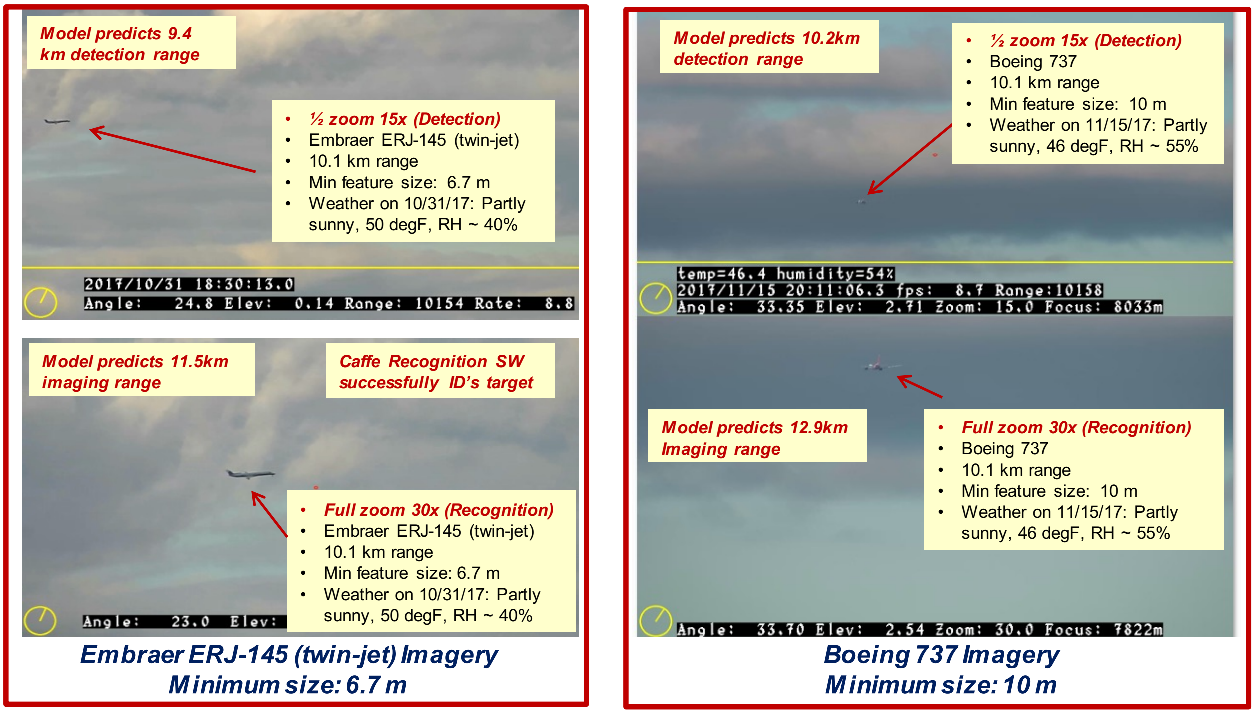


Figure 14. Imagery showing the dual camera/radar tracking system can detect, track and recognize targets of various sizes in real-time at predicted ranges.

Visible Camera Tracking Through Tree Clutter

LW demonstrated that its video imaging software can visually track eagle surrogates through tree clutter at reasonably long ranges. Figure 15 shows a sequence of images of the DJI Phantom tug pulling the eagle balloon silhouette at low altitude at approximately 500 meters range. The eagle surrogate is tracked in real time by the radar that cues the video cameras. The imaging software recognizes the eagle silhouette and successfully tracks it within the yellow box.

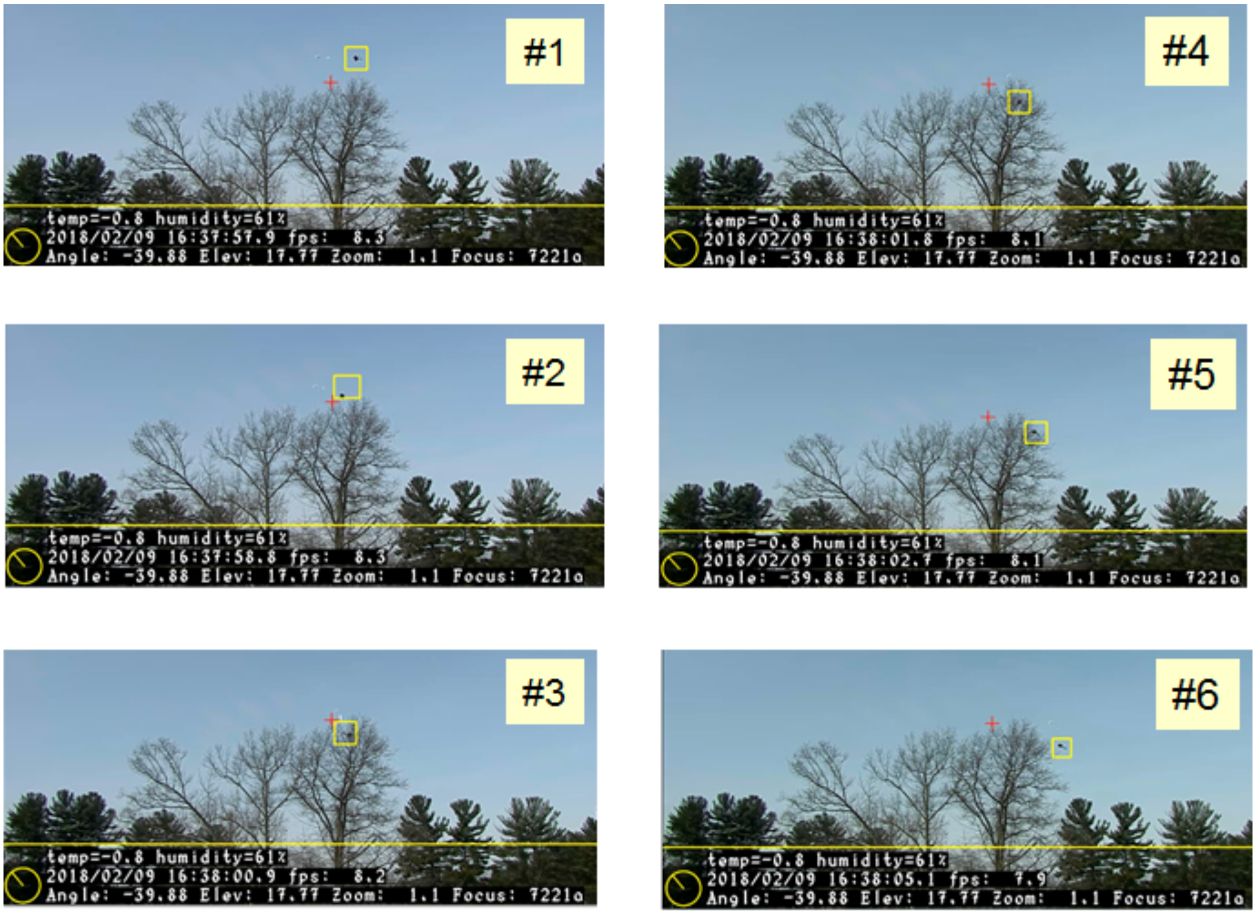


Figure 15.

Task 5.0 Eagle Image Recognition and Classification

Laufer Wind used open-source Caffe Recognition Software to recognize and identify targets.[5] Software integration of the Caffe model was successful, and LW successfully worked at retraining the classifier to recognize birds. Figure 16 shows a photograph of the real-time classifier output as the eagle surrogate balloon is being pulled behind some trees at about 500 meter range. The classifier identifies the balloon image to have the highest probability of a bald eagle, followed by vulture, robin, and magpie in descending probability order. There appears to be no technical show-stoppers for using this system technology to track and correctly visually identify eagles at extended ranges of 1 km.

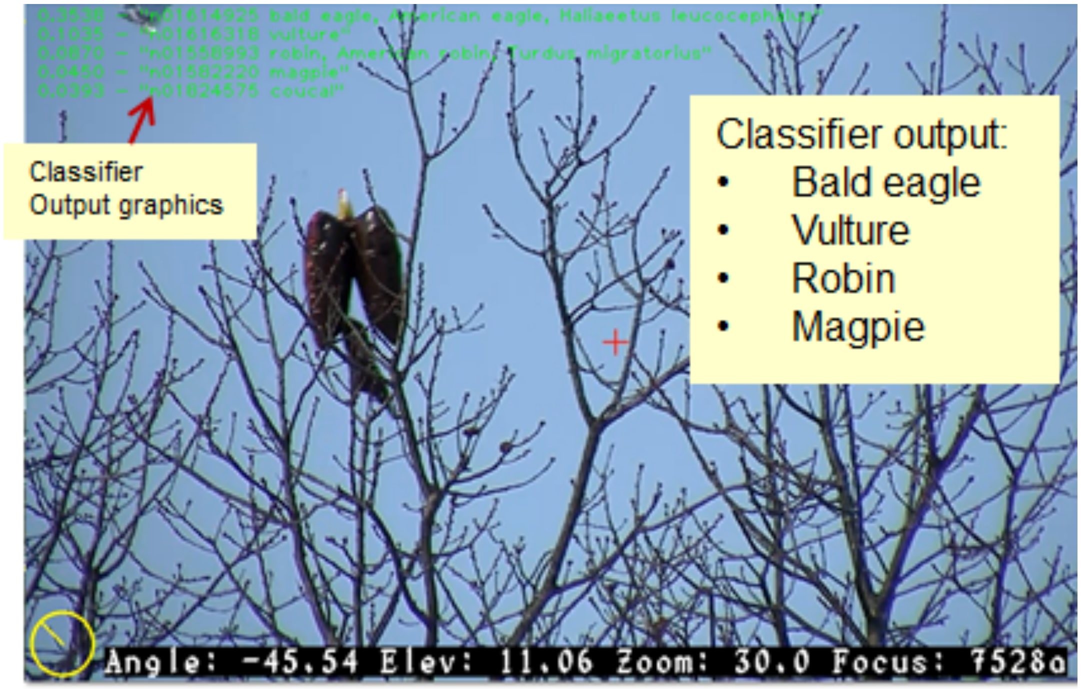


Figure 16. Image classifier output correctly identifies eagle silhouette as a bald eagle as it is being pulled by the DJI Phantom tug.

Task 6.0 Eagle Take System Tests at NREL Wind Technology Center

LW worked with the NREL Wind Technology Center to plan for field tests there. LW submitted a flight test plan shown in Figure 17. The flight pattern was contained within the Wind Technology Center campus.

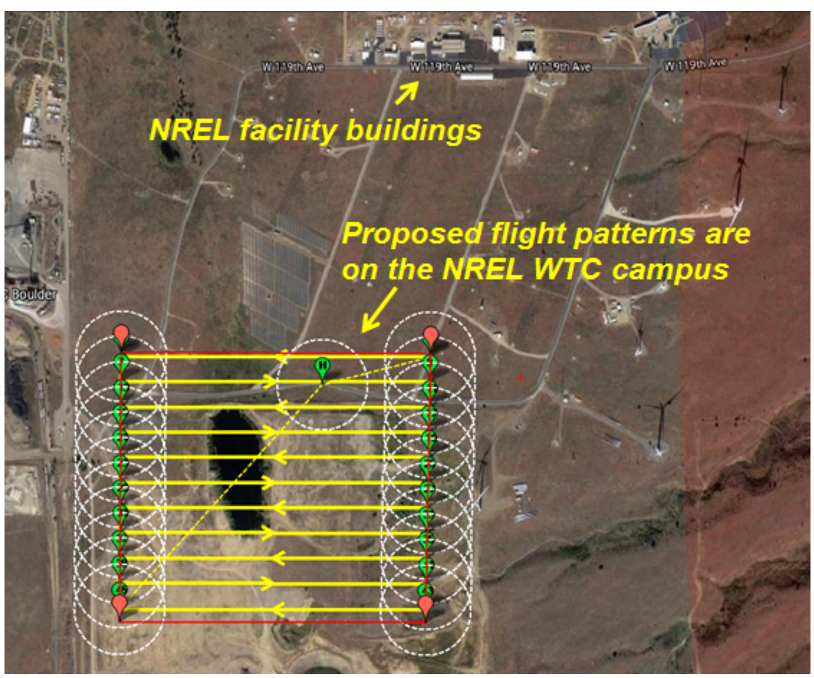


Figure 17. Proposed flight test patterns for evaluating the Eagle Take System performance.

Additional Tasks

LW has terminated the project early and will not be completing further Tasks at this time.

5. Conclusions

A prototype Eagle Take Minimization System was developed and tested that shows capabilities for autonomously detecting, tracking, and visually identifying eagles and other protected avians out to approximately 1 km range with no human-in-the-loop. The Eagle Take Minimization System consisted of networked and sensor-fused commercial-off-the-shelf (COTS) X-band radars, PZT visible cameras and a Central Controller computer. The Central Controller (CC) performed the following functions:

- CC fused airborne target tracks from MD-12 X-band Doppler radars. The MD-12 radar has a demonstrated ability to detect and track eagle-sized targets at ranges of greater than 3 km. The radar can track Cessna-sized aircraft out to a range of 16 km.
- CC used radar tracks to cue Axis Q6115-E PZT cameras towards a target utilizing the cameras' pan and tilt functions. The Axis camera zoom response was not adequate to track fast moving avian targets (>40 mph), so two cameras operating at fixed magnifications of 15x and 30x were simultaneously cued to targets. The 15x camera resolution was adequate to identify and track a target, and the 30x camera provided enough pixel resolution for software to classify and recognize eagle targets at 1 km range. The open source software package OpenCV was used to visually identify and track airborne target sets.
- CC used open source software package BAIR Caffe as the neural net machine learning and stored image database to classify the target image as an eagle or not. The Central Controller maintained a database of confirmed eagle target imagery, initially created in conjunction with the Southeast Raptor Center at Auburn University, but then gradually building its own site-specific image library from identified targets.

Prototype Eagle Take System measurements were performed at Bedford NH using a DJI Phantom drone pulling an eagle balloon silhouette on a tether. The drone's RCS was adjusted to ~ 0.15 sq-m (that simulates an eagle RCS) using metal foils. The X-band radars successfully tracked the drone tug to beyond 3 km, and successfully cued the PZT cameras to the target coordinates in real-time. The cameras and open source software successfully identified the eagle silhouette, tracked it in real-time through clutter scenes (Open CV software) and recognized and identified the silhouette as an eagle (BAIR Caffe) out to a range of approximately 500 meters.

These measurements demonstrate that an Eagle Take Minimization System construct, using networked COTS Doppler radars and PZT cameras, and combined with open source machine learning software, can effectively detect, track, and identify eagles (and other avians) at far enough range so that wind turbines or other moving obstructions can be curtailed to greatly reduce the risk of eagle injury or death.

6. Cost Analysis

Initial LW projections were developed for a model 175 MW wind farm, which would require 4 Radars, 4 Cameras, and 1 Central Controller. Cost for a commercial Eagle Take Minimization System was projected at $850,000, including hardware, software license, installation support (not including physical installation), regulatory support, commissioning, and training. An Eagle Take Minimization System will add to the cost of building a wind farm. Indications from multiple potential buyers in the wind industry suggest the cost will be offset by risk-associated costs of forgoing an available mitigation technology.

Further, LW offered value to customers by providing a bundled service. Adding 40 Obstruction Light Controllers and an upgraded software package to the system described above, would enable wind farms to deploy radar-activated obstruction lighting, mitigating the impact of blinking lights on local communities. The LW cost projection for a 175 MW farm for the dual-purpose system is $935k.

Projections were based on analysis of LW data from manufacturing costs and commercial activity of its Aircraft Detection Systems product.

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