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# A Synchronized Sensor Array for Remote Monitoring of Avian and Bat Interactions with Offshore Renewable Energy Facilities

## Final Report of Results


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## Executive Summary

Wind energy production in the U.S. is projected to increase to 35% of our nation's energy by 2050. This substantial increase in the U.S. is only a portion of the global wind industry growth, as many countries strive to reduce greenhouse gas emissions. A major environmental concern and potential market barrier for expansion of wind energy is bird and bat mortality from impacts with turbine blades, towers, and nacelles. Carcass surveys are the standard protocol for quantifying mortality at onshore sites. This method is imperfect, however, due to survey frequency at remote sites, removal of carcasses by scavengers between surveys, searcher efficiency, and other biases as well as delays of days to weeks or more in obtaining information on collision events. Furthermore, carcass surveys are not feasible at offshore wind energy sites. Near-real-time detection and quantification of interaction rates is possible at both onshore and offshore wind facilities using an onboard, integrated sensor package with data transmitted to central processing centers.

We developed and experimentally tested an array of sensors that continuously monitors for interactions (including impacts) of birds and bats with wind turbines. The synchronized array includes three sensor nodes: 1) vibration (accelerometers and contact microphones), 2) optical (visual and infrared spectrum cameras), and 3) bioacoustics (acoustic and ultrasonic microphones). Accelerometers and contact acoustic microphones are placed at the root of each blade to detect impact vibrations and sound waves propagating through the structure. On-board data processing algorithms using wavelet analysis detect impact signals exceeding background vibration. Stereo-visual and infrared cameras were placed on the nacelle to allow target tracking, distance, and size calculations. On-board image processing and target detection algorithms identify moving targets within the camera field of view. Bioacoustic recorders monitor vocalizations and echolocations to aid in identifying organisms involved in interactions. Data from all sensors are temporarily stored in ring (i.e., circular) buffers with a duration varying by sensor type. Detection of target presence or impact by any of the sensors can trigger the archiving of data from all buffers for transmission to a central data processing center for evaluation and post-processing. This mitigates the risk of "data mortgages" posed by continual recording and minimizes personnel time required to manually review event data.

We first conducted individual component tests at laboratories and field sites in Corvallis and Newport, Oregon, and Seattle and Sequim, Washington. We conducted additional component tests on research wind turbines at the North American Wind Research and Training Center, Mesalands Community College (MCC; General Electric 1.5 MW turbine), New Mexico, and the National Wind Technology Center, National Renewable Energy Laboratory (NREL; Controls Advanced Research Turbines 3 [CART 3] 600 kW Westinghouse turbine), Colorado. We conducted fully integrated system tests at NREL in October 2014 and April 2015. We used only research wind turbines so that we could conduct controlled, experimentally generated impacts using empty and water-filled tennis balls shot from a compressed air cannon on the ground. The ~57 - 140 g tennis balls (depending on water content) were at the upper mass range for bats, but lower mass range for marine birds. Therefore, the ability to detect collisions of most seabirds is likely greater than our experiments demonstrate, but possibly lower for some bats depending on the background signal of a given turbine. Vibration data demonstrated that background signals of operating turbines varied markedly among the CART 3 under normal operation (greatest), GE (moderate), and CART 3 during idle rotation (generator not engaged; least). In total, we measured 63 experimental blade impacts on the two research turbines. Impaction detection was dependent on background signals, position of impact on the blade (a tip strike resulted in the strongest

impact signal), and impact kinetics (velocity of ball and whether the ball struck the surface of the blade or the leading edge of the blade struck the ball). Overall detection percentage ranged from 100% for the "quietest" conditions (CART 3 idle rotation), down to 35% for the noisiest (CART 3 normal operation). Impact signals were detected from sensors on more than one blade (i.e., blades other than the blade struck) 50% - 75% of the time. Stereo imaging provided valuable metrics, but increased data processing and equipment cost. Given the cost of cameras with sufficient resolution for target identification, we suggest mounting cameras directly on the blades to continuously view the entire rotor swept area with the fewest number of cameras. Bioacoustic microphones provide taxonomic identification, as well as information on ambient noise levels. They also assist in identifying environmental conditions such as hail storms, high winds, thunder, lightning, etc., that may contribute to a collision or a false positive detection.

We demonstrated a proof of concept for an integrated sensor array to detect and identify bird and bat collisions with wind turbines. The next phase of research and development for this system will miniaturize and integrate sensors from all three nodes into a single wireless package that can be attached directly to the blade. This next generation system would use all "smart" sensors capable of onboard data processing to drastically reduce data streams and processing time on a central computer. A provisional patent for the blade mounted system was submitted by Oregon State University and recorded by the U.S. Patent and Trademark Office (application no. 62313028). Eventually, technology and industry advances will allow this low cost monitoring system to be designed into materials during manufacturing so that all turbines could be monitored with either a subset or full suite of sensors. As standard equipment on all commercial turbines, the sensor suite would allow the industry to effectively monitor whether individual turbines were causing mortalities or not and under what circumstances. It would also provide real-time evaluation of mechanical and structural integrity of a turbine via vibration, image, and acoustic data streams, thereby permitting modifications in operation to limit environmental or mechanical damage.

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# 1. Introduction

## *1.1. Background*

Wind energy production in the U.S. is projected to increase to 35% of our nation's energy by 2050 (Dept of Energy 2015). Offshore wind is expected to play a significant role in reaching targets (Musial and Ram 2010). The installation of between 50 and 90 GW of offshore wind capacity will require an investment of over $200 billion for construction, operation, and infrastructure development (Musial and Ram 2010). Concerns for environmental impacts, however, especially bird and bat collisions, can add to these costs in the form of construction delays, mitigation, project permitting, etc.

Similar to onshore wind facilities, offshore wind has the potential to affect avian populations through reduction in habitat, disruption of migratory pathways, and injury/mortality through collision (Allison et al. 2008). For many wind facilities, direct impact through collisions is of principal concern. Even low levels of collision mortality are of concern for endangered or protected species. Unfortunately, unless collision and recovery rates are sufficiently high, standard carcass surveys below turbines are unlikely to produce mortality estimates with confidence intervals narrow enough to effectively inform management decisions (e.g., Huso et al. 2015). In the marine environment, standard carcass surveys are not feasible, therefore post-installation impact assessment is problematic. A turbine-mounted detection system with data transmitted back to shore for post-processing is an efficient strategy for long-term assessment of bird and bat casualties in offshore wind energy installations.

## *1.2. Need*

A compact, integrated monitoring system capable of directly observing injury/mortality events 24 hours per day is required to validate site-specific risk models for offshore wind – and could be equally valuable for land-based turbines. Such a system must be relatively simple to deploy on operating turbines and minimize requirements for manual review of data. Because the consequences of injury/mortality depend on the relative significance of the species (i.e., consequences are greater for threatened or endangered species), the system must not only identify injury/mortality events, but also the affected species. Finally, because mass collision events can occur during periods of low visibility (Desholm et al. 2006), the integrated system must be able to operate over a broad range of meteorological conditions and ambient light levels. An integrated impact detection system would also be necessary to validate the efficacy of deterrent or operational measures that are employed to mitigate impact rates.

Several attempts have been made to develop an automatic detection system for avian and bat collision with wind turbines including vibration or acoustic sensing devices and visual- or infrared-spectrum cameras (Desholm et al. 2006, Wiggelinkhuizen et al. 2006, Evans 2012). Desholm et al.'s 2006 Thermal Animal Detection System (TADS) identified detections and taxonomic classification through wing beat analysis and animal size, however, the system required manual review of imagery collected on a pre-determined duty cycle. Wiggelinkhuizen et al.'s 2006 WT-Bird system used vibration sensors to trigger the visual cameras, thereby recording only imagery of greatest interest. Each of the various components (e.g., vibration vs. acoustic sensors, infrared vs. visual cameras) have benefits and drawbacks and no single one is capable of providing all of the information needed to detect impacts and identify the species involved. While previous projects have effectively used multiple sensors, no one project has attempted to integrate all sensors into an automated collision detection and identification system. In this study, we developed and experimentally tested a multi-sensor array for collision detection and identification.

## *1.3. Multi-sensor Array*

Our multi-sensor array consists of three primary sensor nodes communicating with a central controller and data acquisition system (Fig. 1.3.1). The vibration node, composed of accelerometers and contact microphones, provides monitoring for collisions. The optical node, composed of visual and thermal infrared (IR) cameras configured for stereo imagery, provides information for taxonomic classification, as well as information on animal presence and near misses. The bioacoustics node, composed of audio and ultrasonic microphones, provides detection of bird and bat calls/echolocation to aid in species identification, while also providing ambient acoustic information to assess other factors affecting a collision event or otherwise. Temporal coverage of all sensors is continuous, while spatial coverage ranges from omnidirectional (e.g., bioacoustics) to narrow fields of view (e.g., IR camera). Wireless connectivity and on-board battery power for the vibration node allowed sensors to be installed on existing turbines with minimal impact. Both visual and IR cameras were included, as they offer complementary capabilities. Visual cameras provide the most comprehensive taxonomic information and are relatively inexpensive, but are limited to daytime use and favorable meteorological conditions. In contrast, IR cameras are effective in a broader range of environmental conditions and provide higher contrast imagery for target detection, but suffer from lower resolution and higher cost. the three individual types of nodes communicate through a central computer in the nacelle of the turbine. Data from all sensors are stored in individual ring buffers until detection of a collision event, at which point the data surrounding the event is saved. Currently the system is triggered by the vibration node, however, automated event detection could be programmed into all sensors so that each sensor could trigger an event recording. Event data are transmitted back to a central processing location for manual review, thereby limiting the amount of personnel time needed to review sensor data.

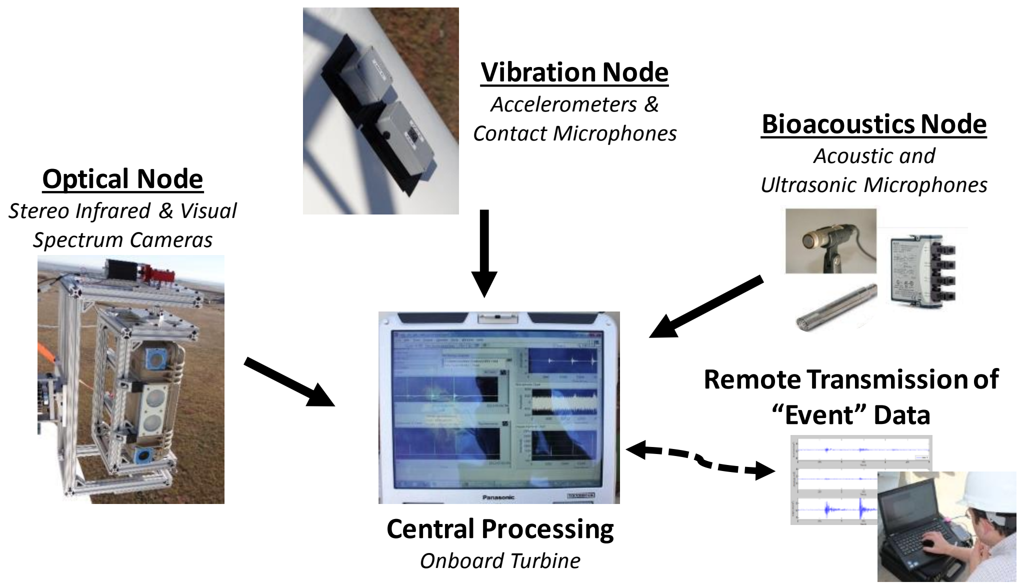



Figure 1.3.1. Diagram of a multi-sensor array for detecting and identifying impacts on a wind turbine showing the three main nodes controlled by a central computer and collision event data transmitted to a remote center for evaluation.

## 2. Study Design and System Description

All system components were initially tested in a laboratory setting before tests on operating turbines. For operational tests, we used two wind research turbines. The use of research turbines allowed us to install devices and have full control of turbine operation, including start-up and shut down, to conduct controlled, artificial impact experiments using tennis balls. We used a 1.5 MW General Electric turbine operated by Mesalands Community College (MCC) at the North American Wind Research and Training Center in Tucumcari, New Mexico, and a 600kW CART 3 Westinghouse turbine operated by the National Renewable Energy Laboratory (NREL) at the National Wind Technology Center in Boulder, Colorado.

### *2.1. Vibration Node*

The vibration node consisted of a paired wireless (UHF) contact microphone and accelerometer positioned at the root of each blade on the turbine. The contact microphone (Sun-Mechatronics USK-40 w/ UZ-10 UHF receiver) was 35mm diameter, 35mm height, weighed 31.7 g, and was powered by an external 3.0V DC cell (Fig. 2.1.1). We used a National Instruments (NI) USB-4431 DAQ to convert the microphone analogue signal to digital. The 3-axis accelerometer (LORD MicroStrain G-Link LXRS with 104-LXRS base station) was 45mm L x 60mm W x 20mm H, weighed 40.8 g, and was powered by external 3.6V DC cell (Fig. 2.1.2). The accelerometer length was oriented with the length of the blade. The paired vibration sensors were attached on the outside of the blade near the root using double-sided tape on the contact surface and black Gorilla® tape along the edges of the boxes to provide an extra firm hold. The double sided tape was commercial 3m plastic tape without a foam core (3m part# 927 or F9460PC were both used). A heat gun was used to heat the blade at the application location to increase tackiness of the double sided tape when attaching to the blade. During tests at MCC in 2013 and NREL in 2014, the sensors were attached on the outside with access from on top of the nacelle (MCC) or using a boom lift from below (NREL 2014; Fig. 2.1.3). During tests at NREL in 2015, the vibration sensors were also placed at the blade roots, but inside the shroud over the hub that allowed easy access for installation from the nacelle (Fig. 2.1.3). Wireless receivers for the contact microphones and

Figure 2.1.1. Wireless contact microphone.

Figure 2.1.2. Wireless accelerometer.

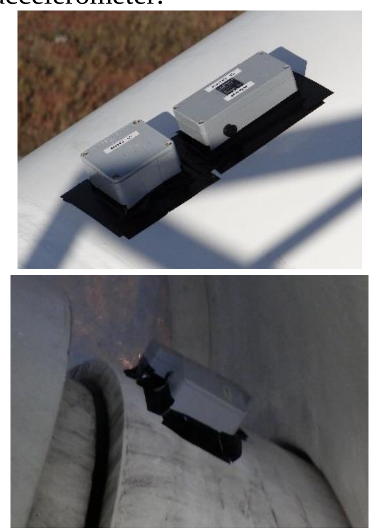


Figure 2.1.3. Placement of the vibration sensors – (top) external or (bottom) inside of the shroud over the hub.


Fig. 2.1.4. Receivers for wireless contact microphones and accelerometers were placed inside the nacelle.

accelerometers were placed inside the nacelle near the hub (Fig. 2.1.4).

*Sampling rates:*

Contact microphones and accelerometers were programmed to sample at 512 Hz and 1000 Hz, respectively, using a custom built LabView graphical user interface. Recording frequency was determined by the desired temporal resolution of impact identification and the capacity of the central computer to record and store desired quantities of data.

## *2.2. Optical Node*

While IR cameras provide excellent contrast for target detection, they have limited resolution in comparison to visual spectrum cameras. The generation of uncooled microbolometer-based IR cameras at the time of this study had a maximum resolution of 640x480 (0.3 Megapixel – Mpx) in comparison to visual spectrum cameras approaching 10 Mpx resolution. Consequently, in selecting a camera lens there is a significant trade-off between the percentage of the rotor swept area being imaged and the ability to detect a target (e.g., a “fish eye” lens with a wide field of view may have insufficient resolution to detect targets over the intended operating range). We evaluated three types of cameras for the optical node: 1) thermal infrared (FLIR A655sc), 2) visual spectrum standard (Allied Vision Technology Manta 201- C), and 3) visual spectrum “smart” cameras with onboard processing capabilities (Ximea Currera- RL50C). The stereo-infrared and stereo-visual cameras were enclosed in a weather-resistant housing (Fig. 2.2.1) and were integrated into the sensor array via a LabView visual interface. Dimensions of the housing was 0.5m W x 0.2m H x 0.4m D and the cameras and housing combined weighed 12 kg. The optical node was secured within a pan-and-tilt frame (Fig. 2.2.2) that was attached to the railing on the CART 3 turbine at NREL (Fig. 2.2.3). The pan-and-tilt frame was 0.9m W x 0.8m H, and 0.4m D. The combined frame with drive motors weighed 50 kg, but could be broken down into smaller 15 kg modules for transport up the tower and onto the nacelle. The worm gears and frame were sized to withstand gusts of up to 140 mph with the system in an adverse orientation. The pan-and-tilt frame was controlled using a LabView virtual instrument (VI) on the central computer.

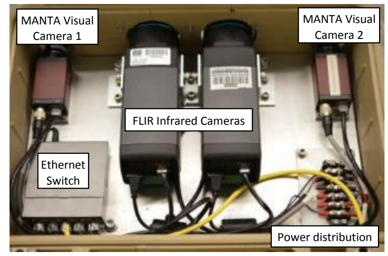



Figure 2.2.1 Stereo-infrared and stereo-visual cameras enclosed in a weather-resistant housing.

Figure 2.2.2 Pan-and-tilt frame for optics node.


Figure 2.2.3. Pan-and-tilt frame attached to railing on nacelle of Cart 3 turbine at NREL.

Fig. 2.2.4. Smart cameras with onboard image processing ability.

The optical node required 120 V AC power, transformed to 12 V DC. In operation, the optical node itself draws < 100 W of power. The pan-and-tilt motors require 120 V AC and can draw up to 500 W of power.  In addition to power supply, the optical node required an Ethernet connection to the central computer.

The smart cameras (Fig. 2.2.4) operated independently, not in stereo.  These cameras were used on an experimental basis with the anticipation that they would prove valuable in a subsequent design of a miniaturized system.  For the initial design, however, we preferred that all sensors be under control of the central computer that was running the sensor integration and triggering software.

*Sampling rates and field of view:*

The infrared cameras had a resolution of 640 x 640 and sampled at 12 frames per second (fps) with a 15° field of view lens.  The stereo visual Manta cameras had a resolution of 1624 x 1234 and sampled at 6 fps with a 52° field of view lens.  The Ximea smart cameras had a resolution of 2650 x 1920 and sampled at 15 fps with a 19.4° or 25.7° field of view lens.

Figure 2.3.1. Independent bioacoustic recorder.

Figure 2.3.2.  Integrated bioacoustics node showing the microphone (top), analogue to digital converter (middle), and microphone power module with filter (bottom).

## *2.3. Bioacoustic Node*

The bioacoustics node consisted of one microphone for bird calls and ambient noise, a second ultrasonic microphone for bat echolocation calls. Ultrasonic microphones are sensitive to sounds greater than 20 kHz, which is typical of bat echolocation calls.  We initially used an stand alone acoustic recorder that had self contained power, microphone, analogue to digital converter, filter, and data storage (Wildlife Acoustics SM3 Bat/Bird; Fig. 2.3.1).  This recorder was used during our initial, tests at NREL, however at that time, the bioacoustics were not integrated into the array. During our final tests at NREL, we used a completely redesigned bioacoustic node that was fully integrated with other sensors in the array (Fig. 2.3.2).  The components of the integrated bioacoustics node included: 1) a general purpose electronic piezoelectric microphone for audio signals powered by a 4 mA 1-Channel CCP Power Module with A-weighting filter (G.R.A.S. Sound and Vibration A/S); 2) a Knowles FG Electret ultrasound microphone for ultrasonic signals (Avisoft Bioacoustics); and 3) a National Instruments NI-9223 DAQ analog to digital converter.  Although we designed the system to record both frequency ranges, we used only the acoustic microphone during impact testing given that all tests were conducted during daylight hours, negating potential to record bat echolocation calls.  Microphones were mounted both inside and outside the nacelle during tests on the CART 3 turbine at NREL.

*Sampling rates:*

The four channel NI-9223 DAQ can sample at 1 MHz channel$^{-1}$.  The sampling frequency for recordings was approximately 5-10X the frequencies of the anticipated vocalizations or echolocation.  Sampling frequency was 200 kHz for the acoustic microphone and 500 kHz for the ultrasonic microphone.

### *2.4. System Integration and Data Acquisition*

We used LabView system design software operating on the central computer for individual component control and data acquisition (Fig. 2.4.1). We created a custom LabView VI to control instruments from each sensor node, including sampling frequency and duration. These individual sensor node VIs were embedded within an overarching system control VI that triggered data collection from all sensors and stored the data in a standardized format on the central computer separately for each triggering event.

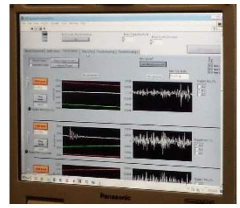


Figure 2.4.1. Example window of custom built LabView virtual instrument user interface.

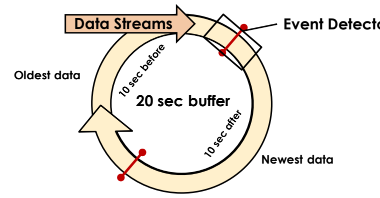



Figure 2.4.2. Ring buffer architecture for multi-sensor data recording, event detection, and data storage.

The central computer controlling the system was placed in the nacelle and controlled by a second computer at ground level during operational testing via an Ethernet connection and remote desktop. Data from each sensor streamed continuously to the central computer in the nacelle during system operation. The volume of data from all sensors, especially the optical node, was too large and time consuming to archive data continuously. To manage this volume of data, we used a ring buffer architecture to save data from impact events. Without a triggering event, the ring buffer was continually overwritten. Once an event recording was triggered, however, data streams from all sensors were written to disk for a specified period of time before and after the event (Fig. 2.4.2). For our test purposes, we chose 20 second buffers for all sensor nodes, with the impact event nominally centered in the buffer. In a non-experimental setting, additional extended recording time for the bioacoustics could capture vocalizations or echolocations from the species of bird or bat involved in a collision, provide a relative assessment of how many individuals were nearby, and assess ambient environmental conditions that may have led to the collision or a possibly false positive detection (e.g., hail, lightning, etc.). The software allowed individual control of the buffer size for each node, therefore the user could determine the amount of data to be stored for each sensor before and after an event trigger.

### *2.5. Impact Event Detection and System Trigger*

We tested several event detection and system triggering mechanisms ranging in complexity. Automated detection algorithms tested included continuous wavelet transformation (Flowers et al. 2014, Flowers 2015). These more complex algorithms were tested during retrospective analyses of impact event data collected during lab or field experimentation. Both approaches showed promise, but require further development to function in a fully automated, operational setting. We did use a simple automated threshold trigger during static integrated system tests on a non-operational turbine (CART 3) at NREL. This automated threshold triggering test verified the full functionality of the integrated system software and provided a proof of concept for inclusion of more complex real-time detection algorithms during future developments. We used a manual trigger implemented through the system control VI software for all operational tests of the integrated system.

### *2.6. Experimental Impacts*

We used a compressed air cannon capable of shooting tennis balls to create experimental impacts on research turbines (Fig. 2.6.1). The propellant source for the canon was an air compressor with a pre-pressurized air tank. The regulator for the air cannon was set to 115 psi (the max pressure for the electric valve). The launcher was controlled using an off/on toggle safety switch and a momentary switch. The air cannon is operated by holding down the momentary switch to charge the air cannon's air tank and then releasing the momentary switch to open the valve and launch the tennis ball. Switches controlling the electric pneumatic valve were powered by two 12V DC batteries connected in series (24V DC). The cannon is barreled to shoot a standard tennis ball that weighted ~57 g empty (used at MCC & NREL) or ~140 g filled with water (MCC only). Empty tennis balls were similar in mass to the largest bats and smallest seabirds (Fig. 2.6.2). During some tests at NREL, we soaked tennis balls in warm water to provide a stronger thermal and residual impact signal for the IR cameras.

Figure 2.6.1. Compressed air cannon used to create experimental impacts on research turbines.

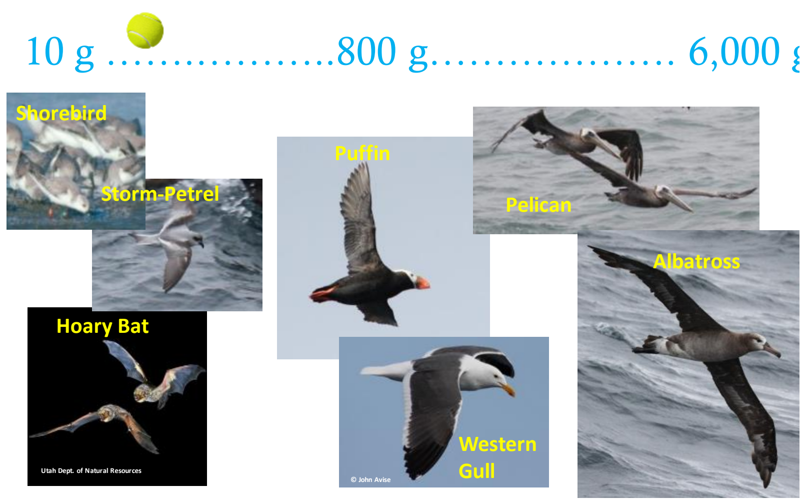



Figure 2.6.2. Mass of an empty (i.e., not water filled) tennis ball used in experimental wind turbine impact tests relative to large bats and small to large seabirds

### *2.7. Project Timeline*

The first three years of the project primarily involved refining system design and individual component tests (Table 2.7.1). In designing the system, we relied on considerable input on many aspects of the system and performance requirements from advisory panel members representing industry and agency perspectives, as well as science and biological expertise. Several key modifications resulting from advisory panel input include: 1) stereo camera configuration to calculate size and distance to object, 2) integration of the bioacoustics node into the sensor array because of its potential contribution to impact detection (Evans 2012), and 3) importance of identifying individual species of birds or bats interacting with the turbine, therefore requiring high resolution imagery. These considerations led to extra design, laboratory, and field testing (stereo cameras and integrated bioacoustics) and sensor mounting configuration on the turbine. To ensure success of these efforts, we made three rather than the one planned visits for testing at NREL and added a stereo camera test in collaboration with Pacific Northwest National Laboratory scientists in Sequim, WA. We required a 1-year extension, for a total of 4-years, to complete all of the project tasks (Table 2.7.1).

Table 2.7.1. Timeline for major tasks of the project. Total project period was October 1, 2011-September 30, 2015.

| | Component | | | | |
|---|---|---|---|---|---|
| Task | Vibration | Optic | Bioacoustic | Location | Performance Period (Budget Periods 1-4) |
| Advisory panel meetings | | | | Newport & Corvallis | 1st meeting in BP1<br>2nd meeting in BP3 |
| Individual component testing and calibration | X | X | X | Seattle, Corvallis, Newport | BP1-BP4 |
| Target identification #1&2 | | X | | Newport | BP2, BP3 |
| Test site assessment | X | X | X | NREL, NWTC | BP2 |
| Collision event detection (individual components, non-integrated) | X | | | MCC, NAWRTC | BP3 |
| Target identification (stereo) | | X | | Sequim | BP3 |
| Collision event detection (individual components, non-integrated) | X | X | X | NREL, NWTC | BP3 |
| Collision event detection (fully integrated system) | X | X | X | NREL, NWTC | BP4 |

# 3. Results

## *3.1. Vibration Node*

### *Laboratory Testing*

Initially the vibration node was tested in the laboratory using a mechanical shaker (Fig. 3.1.1). With the accelerometer on a bar attached to the shaker, gently tapping the bar with a screw driver served as an impact signal. The accelerometer signal from this test is a 10hz sine wave (57 mVrms) combined with white Gaussian noise (80 mVrms). This results in a very noisy signal with periodic characteristics, much like the actual wind turbine data we received (Fig. 3.1.2). Once low pass and high pass filters of discrete wavelet transformations (Coiflets 5) are applied, a clear impact signal is evident (Fig. 3.1.2). The high pass filters out the white noise (which was a bit more dampened by the bar than expected) and most of the periodic signal. The filtering and detection algorithm produced good results on artificial and actual wind turbine data with impact signals, however, additional refinement is necessary for operation in real-time.

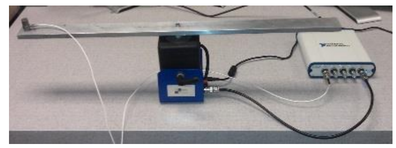


Figure 3.1.1. Accelerometer mounted to an aluminum bar atop a shaker. An input/output module controls the shaker and receives data from the accelerometer.

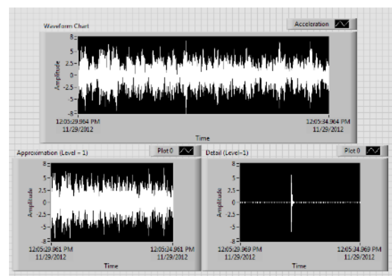


Figure 3.1.2. (top) Raw accelerometer data from shaker. (lower left) Data after low pass filtering and (lower right) impact signal after a combined low then high pass filtering using discrete wavelet transformations.

### *Archived turbine operation data*

We obtained accelerometer data from turbines operated by Floating Power Plant A/S and NREL to provide background operational signals in which we could insert simulated impact signals to test detection algorithms. Data from Floating Power Plant were collected at too low of a frequency and, unfortunately, could not be used for these purposes. Some data from the NREL CART 3 turbine, however, were collected at 400 Hz and, therefore, beneficial for continued laboratory testing and calibrating of the impact detection algorithm.

### *Tests on Turbine*

We conducted operational tests in 2013 at MCC and in 2014 and 2015 at NREL. A summary of data collected during these tests is provided in Tables 3.1.1 and 3.1.2.

Table 3.1.1 Tests performed on the MCC GE turbine with only vibration sensors mounted on the turbine (Ximea smart cameras collected some image data from the ground), 9-13 December 2013. Sample sizes (# of recordings) are shown for each sensor node (n = 630 recordings from individual sensors). All recordings were using a manual trigger.

| Description | Sensor Vibration |
|---|---|
| Turbine start-up, shut-down, and engaging generator sequences | 22 |
| Turbine Normal Operation, single ball shot from air cannon on ground and impacting a blade | 17 |
| Turbine Normal Operation, single ball shot from air cannon on ground and impacting the tower | 11 |
| Turbine Normal Operation, single ball shot from air cannon on ground and impacting the tower and a blade | 6 |
| Total = | 55 |
| Total blade impacts = | 23 |

Table 3.1.2. Tests performed on the NREL CART 3 turbine with all sensor components, 22 - 23 October 2014 and 13 - 17 April 2015. Sample sizes (# of recordings) are shown for each sensor node (n = 2,252 recordings from individual sensors – 6 vibration sensors, 4 optical, 1 bioacoustic). Due to varying wind conditions and greater background noise of the older CART 3 turbine, we ran the turbine under several modes. Recordings are summarized among the different operational modes.

| | Sensor | | | |
|---|---|---|---|---|
| Description | Vibration | Optic | Bioacoustic | Total |
| Turbine Normal Operation[1], start-up and shut-down sequences | 13 | 1 | 9 | 23 |
| Turbine Idle Rotation[2], start-up and shut-down sequences | 2 | 0 | 2 | 4 |
| Stationary blade, single ball hand thrown from the nacelle | 21 | 19 | 2 | 42 |
| Stationary blade, multiple balls (2-4) hand thrown from the nacelle | 3 | 3 | - | 6 |
| Stationary blade, single ball shot from air cannon on ground (manual trigger) | 2 | 20 | 21 | 43 |
| Stationary blade, single ball shot from air cannon (automatic trigger) | 4 | 3 | 4 | 11 |
| Turbine Normal Operation[1], single ball shot from air cannon on ground (manual trigger) | 6 | 6 | 6 | 18 |
| Turbine Idle Rotation[2], single ball shot from air cannon on ground (manual trigger) | 4 | 4 | 4 | 12 |
| Total = | 55 | 56 | 48 | 159 |
| Total blade impacts (stationary) = | 30 | 45 | 27 | |
| Total blade impacts (operational) = | 10 | 10 | 10 | |

[1]The generator is engaged during normal operation.

[2]The wind speed is too slow to engage the generator during idle rotation. Operating the CART 3 in this state was beneficial to our tests because the background noise of the turbine was much quieter than the intermediate noise from the GE turbine at MCC and the most noise from the CART 3 during normal operation.

*Static Impact Tests*

We initially tested sensor operation and recorded impact signals of a tennis ball thrown by hand from atop the nacelle and impacting a stationary blade. The 3 axes accelerometers showed the strongest signal in "Z" or out of plane axis of the blade (Fig. 3.1.3). The paired contact microphone and accelerometer both showed a clear signal of the impact (Fig. 3.1.4). Repeated blade impact signals are distinctive from three tennis balls sequentially thrown from the nacelle (Fig. 3.1.5).

*Dynamic Impact Tests*

We first obtained background levels of turbine operation by recording sequences of turbine start-up, shut down, and generator engagement for both the GE and Cart 3 turbines (e.g., Fig. 3.1.6). This along with prior CART 3 operational data obtained from NREL provided vital information on characteristic periodic and non-periodic vibration signals that an impact detection algorithm must account for. Furthermore,

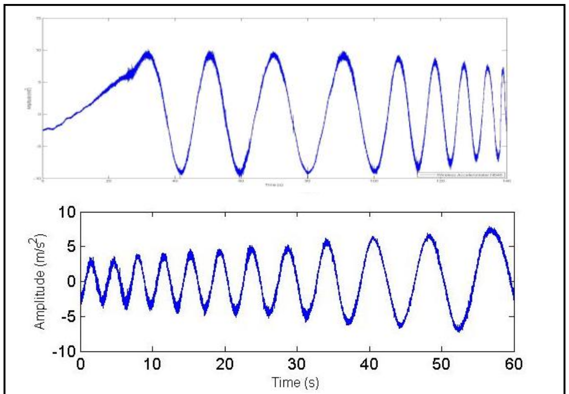



Figure 3.1.6. Accelerometer data from a single blade (GE) during turbine startup (top) and shut down (bottom).

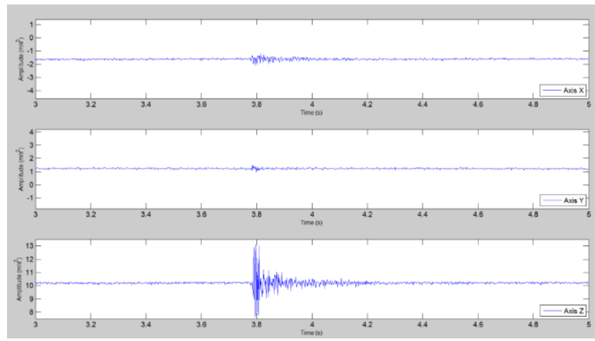



Figure 3.1.3. Data from the three axes of one accelerometer on a single, stationary blade (CART 3) showing the impact of a single tennis ball hand thrown from on top of the nacelle. The strongest signal is in the Z axis (bottom).

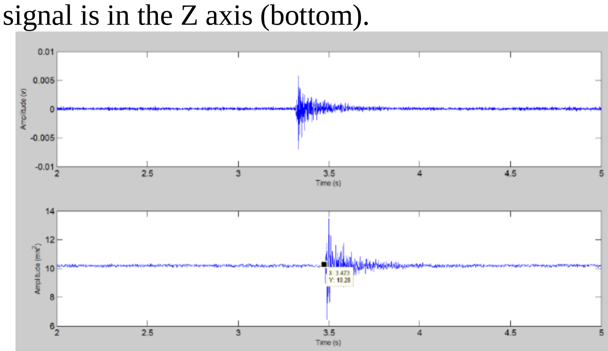


Figure 3.1.4. Data from a contact microphone (top) and accelerometer (bottom) on a single, stationary blade (CART 3) showing the impact of a single tennis ball hand thrown from on top of the nacelle. The impact signals are slightly offset because the time recording of the two sensors were not perfectly synchronized.

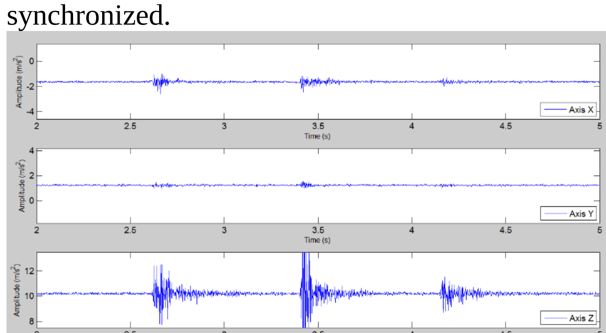



Figure 3.1.5. Data from one accelerometer on a single stationary blade (CART 3) showing three sequential impacts from three tennis balls thrown from the nacelle.

these measurements clearly demonstrated striking differences in background noise levels between the GE and CART 3 turbines and the different operational modes of the CART 3. It was clear that the smaller, but older CART 3 had larger background vibration signals through which to discern impact signals (Fig. 3.1.7). The greater background vibrations of the CART 3 could potentially mask impact signals of less kinetic energy that were detectable on the larger GE (MCC). Indeed, we observed that fewer impacts could be visually detected in the accelerometer data from the CART 3 at NREL than what we had expected based on results from impact tests on the GE at MCC. Due to low wind occurrence during our

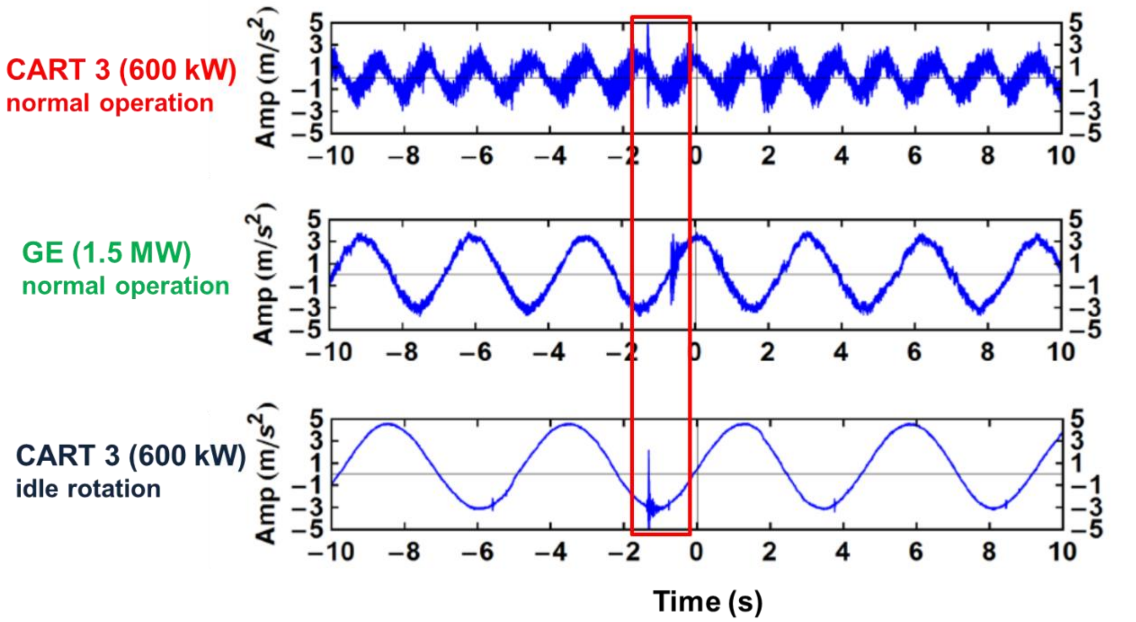



Figure 3.1.7. Increasing levels of background "noise" in out-of-plane (Z) axis accelerometer data from the CART 3 600 kW turbine during normal operation (generator engaged), the GE 1.5 MW turbine during normal operation, and the CART 3 during idle rotation (generator not engaged). The frequency of oscillations indicates the CART 3 under normal operation is rotating at the highest rpm, followed by the GE, then the CART 3 during idle rotation.

final test at NREL, we also operated the CART 3 turbine in idle rotation (generator not engaged). The CART 3 turbine operating in idle rotation had much lower background signals compared to both the CART 3 and GE during normal operation (Fig. 3.1.7). Low background signal of the CART 3 during idle rotation is in part because the generator was not engaged, therefore less load on the gearbox, but also because the blades were rotating at a lower speed than both the CART 3 or the GE under normal operation - as indicated by the reduced frequency of the sine wave. Fortunately, the two operational modes of the CART 3 turbine plus the normal operational mode of the GE provided three background signal scenarios for us to test impact signal detection.

In total, we measured 23 blade impacts on the GE turbine under normal operation, six blade impacts on the Cart 3 during normal operation, and 4 blade impacts on the CART 3 during idle rotation (Tables 3.1.1, 3.1.2, Fig. 3.1.8). Impaction detection is dependent on background signals, position on the blade section, and impact kinetics. Overall detection percentage ranged from 100% for the "quietest" conditions (CART 3 idle rotation), down to 35% for the noisiest (CART 3 normal operation; Fig. 3.1.8).

Impact signals were detected from sensors on more than one blade (i.e., blades other than the blade struck) 50% (CART 3 during normal operation) to 75% (GE during normal operation and CART 3 during idle rotation) of the time.

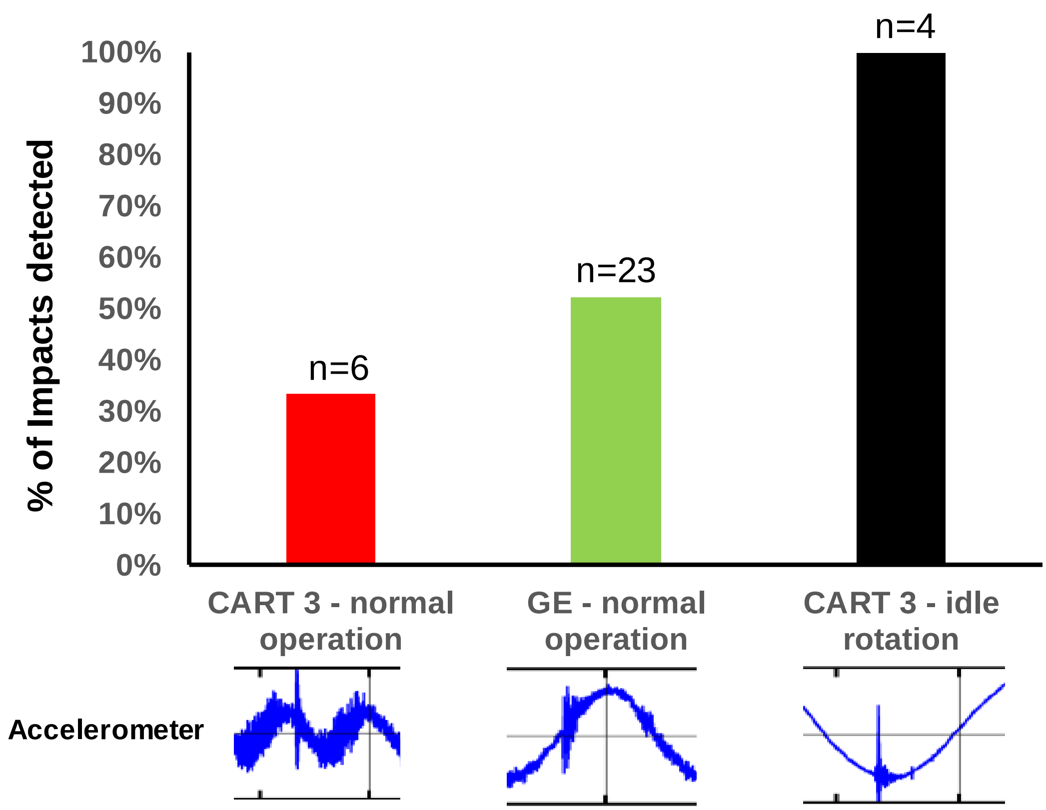



Figure 3.1.8. Percentage of turbine blade impacts from a 57 g tennis ball shot from a compressed air cannon on the ground that were detected by accelerometers or contact microphones mounted on blade roots (one accelerometer and one contact microphone on each blade). Data are from two different turbines with one of the turbines operating in two different states providing different background signals (accelerometer graphs below x-axis; see Fig. 3.1.7 for explanation)

## *3.2. Optical Node*

### *Laboratory Testing*

We first determined lens focal length that would allow identification of target species of birds and bats that would be expected offshore of North America. For wind turbines deployed on the west coast of the United States, a signature avian species of regulatory concern is the marbled murrelet (*Brachyramphus marmoratus*). These birds are quite small relative to other seabirds (10 cm body size) and can fly at speeds up to 44 m/s (100 mph) and, therefore, is a good minimum target identification size. The candidate locations for IR camera are on the turbine nacelle or the tower. Prior experience suggests that the camera should not be oriented towards the water surface since small targets will be indistinguishable from sea clutter (i.e., variations in emissivity associated with wave propagation and breaking). In the following example, three lenses (15$^o$, 25$^o$, 45$^o$ field of view) are considered for an IR camera either: 1) Mounted 20 m above the water line on the tower, oriented towards the sky or 2)

Mounted on top of the nacelle and oriented towards the sky. Neglecting lens distortion, at a given distance ($D$) from the camera, the width ($L$) of the field of view is given as a function of the lens angle ($\theta$) by the trigonometric relation

$$L = 2D\tan\left(\frac{\theta}{2}\right).$$

The size of a pixel at distance $D$ is then given as $L/R_x$, where $R_x$ is the horizontal resolution (i.e., 640 pixels). The number of pixels spanning a marbled murrelet can then be readily calculated from the murrelet's body size.

For the example, we consider the case of Siemens SWT-6.0-154 (6 MW) offshore wind turbine, representative of the scale of an offshore turbine making use of the monitoring system. The turbine blades for the SWT-6.0-154 are 75 m long and the hub is 4 m in diameter. Hub height is selected in a site-specific manner and here we assume a hub height of 116 m (consistent with the hub height of the prototype SWT-6.0-154). Target resolutions for each lens and camera orientation combination (6 total) are shown in Figure 3.2.1. Target detection is unlikely to be possible if there are less than 3-4 pixels spanning a target.

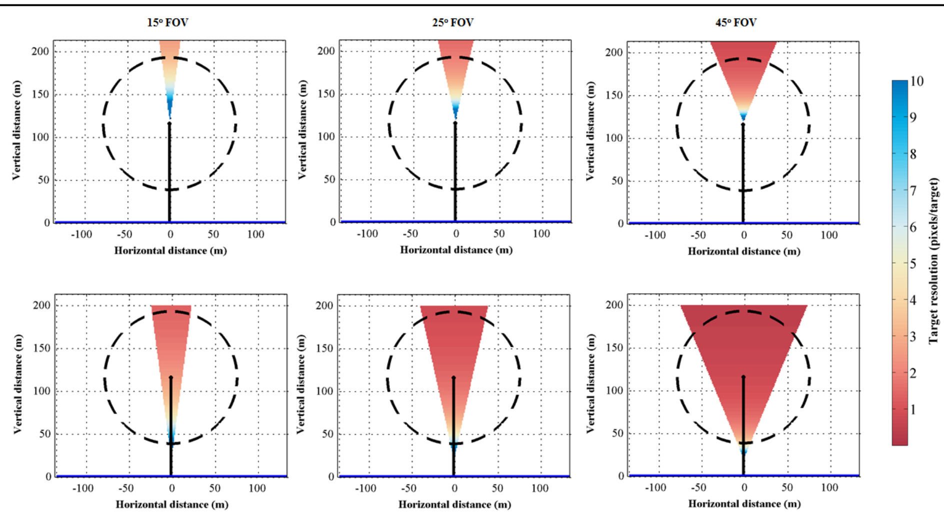



Figure 3.2.1. Trade-off between percentage of rotor imaged and spanwise target resolution for a 10 cm marbled murrelet (i.e., potential for detection) for three lens fields of view and two camera positions (upper – top of nacelle; lower – 20 m above sea surface). Dashed black line indicates extent of rotor sweep for Siemens SWT-6.0-154. Solid black line indicates tower height.

These results suggest that only an IR camera with a narrow field of view (e.g., 15° lens) would allow for target detection over the length of a turbine blade. Coverage with this narrow angle lens, however, is restricted to a small portion of the rotor swept area, requiring multiple cameras to achieve sufficient coverage. Conversely, a 45° lens could cover the majority of the rotor swept area. In this configuration, detection of a murrelet is unlikely at appreciable distances, but detection of larger seabirds is feasible.

A second metric for target detection is the number of frames containing a target. If a murrelet is assumed to be traveling in a straight line in a horizontal plane, then the number of captured frames is given by

$$\frac{L}{u_{target}} x F$$

where $\underline{u}_{target}$ is the target speed (m/s), $F$ is the camera frame rate (Hz), and $L$ is as previously defined. The FLIR A655sc can record full resolution frames at up to 50 Hz. Marbled murrelets are likely to fly at speeds between 17 and 44 m/s (40-100 mph). Figure  shows the number of frames that would be captured under this idealized scenario for two lens angles. Due to the wider field of view, the 45° lens is able to capture many more frames containing a target than the 15° lens at equivalent distances and target speeds. These results suggest that high-speed target detection using a 15° lens may be challenging at distances less than 10 m from the camera (i.e., the target will be present in relatively few frames). This is balanced against a high number of pixels per target at close range, which will facilitate detection and identification.

In summary, analyses suggest that if marbled murrelets are a species of concern, then target detection

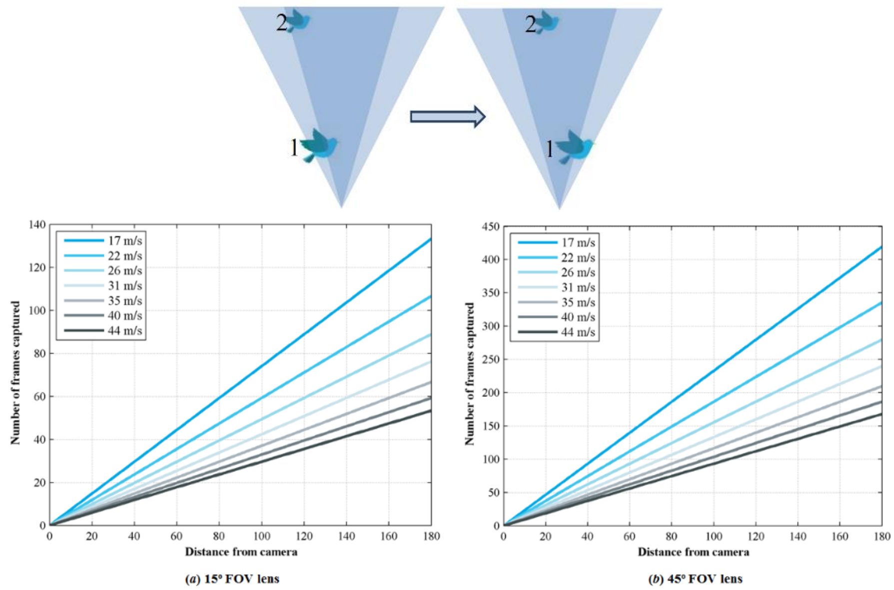



Figure 3.2.2. Number of frames captured as a function of target speed and distance from camera for two lenses.

will be best achieved by a narrow angle lens (i.e., 15°). In order to achieve significant rotor and tower coverage this will, however, require on the order of ten cameras – or twenty for stereo imaging – per turbine. For locations where larger species are likely to be of greatest concern (e.g., albatross in mid-outer continental shelf deployments), a wider angle lens may be effective and preferred.

Early in the project, we pursued stereo imaging techniques upon recommendation of our advisory panel. Stereo imaging allowed us to determine target size, speed, and position, but also increased the complexity of the optical node. Stereo imaging required camera calibration (Fig. 3.2.3) and software permitting target identification and tracking. We were successful in using stereo imaging to measure size and distance of bats (Fig. 3.2.4) and birds (Fig. 3.2.5) during field trials in Sequim Washington.

*Experimental Turbine Tests*

We completed 18 tests using single tennis balls soaked in warm water to provide a thermal signature for IR cameras while in flight and during impact (Table 3.1.2). The warm water left a strong thermal signature on the blade at the point of impact (Fig. 3.2.6). The point of impact was less evident, but still detectable with the visual cameras (Fig. 3.2.6). We collected IR and visual imagery from 20 impacts on a stationary blade with a single tennis ball shot from the ground using a compressed air cannon (Table 3.1.2). In addition to inherent differences in IR and visual images, we were able to document the effect of different camera resolution and frame rates in identifying the object and capturing the object near the moment of impact. The IR cameras were higher frame rates (12 fps) than the visual cameras (6 fps), allowing us to capture imagery near the moment of impact for IR, but not visual cameras (Fig. 3.2.7). For the purposes of this project, we recommend using 15° field of view, similar to the IR camera, and $\geq$ 12 fps. The lower resolution of the IR camera (640 X 480) was somewhat compensated by the longer focal length (narrower field of viewer) to help identify the object (Fig. 3.1.7). The thermal signature of the warmed tennis ball and water left on the blade at the point of impact was also evident on the moving blade in the IR image (Fig. 3.2.7).

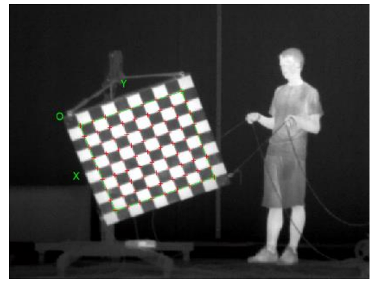


Figure 3.2.3. Stereo camera calibration chart.

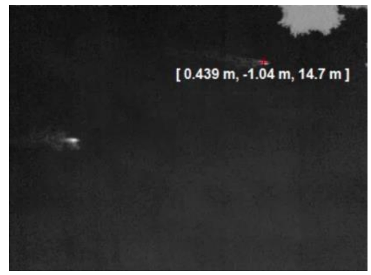



Figure. 3.2.4. Target tracking (50 fps) and distance calculation of a bat. Two bats are in image. Species was either silver-haired, California myotis, or little brown – all were present in audio recordings during image capture.


Figure. 3.2.5. Target tracking (12 fps) and distance calculation of a Brewer's blackbird.

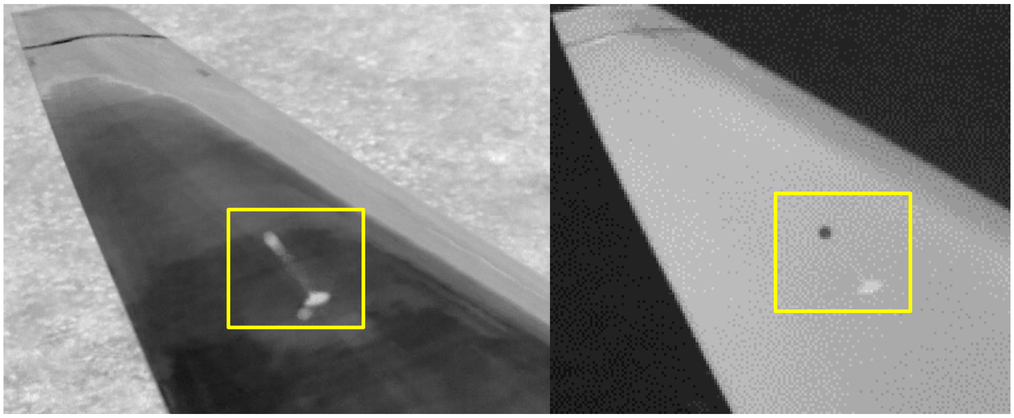


Figure 3.2.6. Infrared (left) and visual (right) image of a tennis ball soaked in warm water bouncing off a stationary blade. IR and visual cameras are mounted side-by-side (Fig. 2.2.1). The IR image (left) was taken with a resolution of 640 X 480 at 12 fps and 15° field of view lens. The visual image (right) was taken with a resolution of 1624 X 1234 camera at 6 fps and 52° field of view lens.

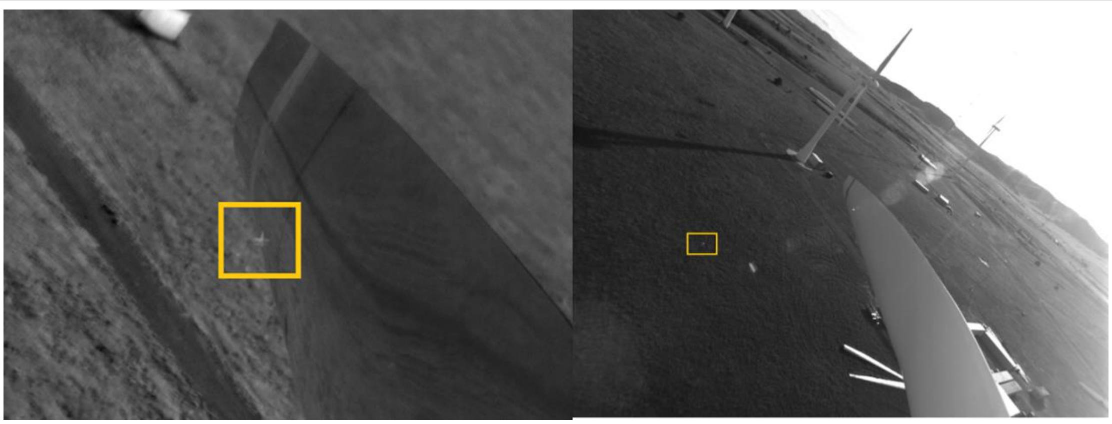


Figure 3.2.7. (Left) IR camera showing impact to a stationary blade of a tennis ball fired from an air cannon on the ground. (Right) Visual camera showing the ball falling away after the same impact event. The IR image (left) is taken at 12 fps, allowing us to capture the moment of impact The visual image (right) is taken at 6 fps and did not allow us to capture the moment of impact.

During fully integrated system tests at NREL, tennis balls were fired from the upwind side of the blades due to safety constraints. With cameras mounted from the top of the nacelle looking at the downwind side of the blade, few images captured a tennis ball traveling through the air or striking the blade, due to the blade itself visually obstructing the event. This experimental difficulty demonstrates the significance of camera placement in target identification. An alternative camera location is to mount cameras directly on the blade, near the hub looking outward. Each blade is always in full view, and this configuration allows shorter imaging distances, higher target resolution, and minimizes the number of cameras needed. We tested this camera location using a GoPro camera mounted to the blade of the GE turbine at MCC (Figure 3.2.8). Additional testing is needed to determine proper focal length, resolution, and frame rates for blade mounted cameras, data and power integration, as well as camera placement on blades (e.g., center of chord, leading or trailing edge, windward, leeward, or both sides), but we feel this is the most promising direction for the next generation impact system detection design (see Chapter 4. Next Generation System Design & Commercialization).

Figure 3.2.8. Views from a GoPro camera mounted at the root of the blade with sky and ground background on the GE turbine at MCC. Placement of cameras on turbine blade is a likely solution to provide the resolution needed for target identification while minimizing the number of cameras needed to cover the entire rotor swept area.

*3.3. Bioacoustic Node*

Since it was highly unlikely that we would record bird or bat vocalizations or echolocations during our short-duration experimental tests, we used audio recordings of turbine operation and impact sounds to demonstrate successful operation of the bioacoustics node. These results highlighted the additional value of the bioacoustics node to provide ambient acoustic information that could help identify an impact signal or possible reasons for false positive impact signals from the vibration node, such as rain, large hail stones, lightning, etc.

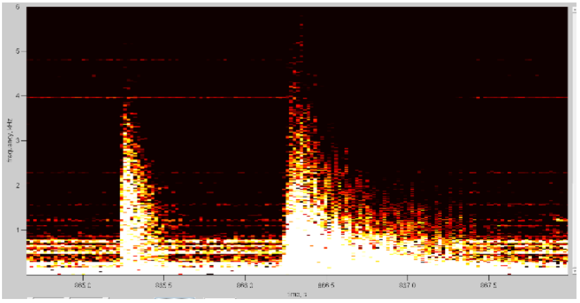


Figure 3.3.1. Spectrogram from an acoustic recorder located inside the nacelle of the CART 3 turbine during a stationary blade impact test. The left signal is the compressed air cannon being fired from the ground and the right signal is the impact of the tennis ball on the blade.

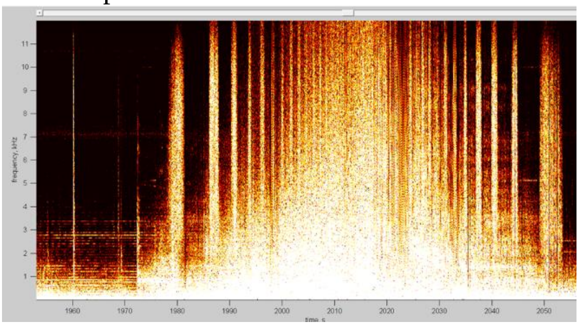


Figure 3.3.2. A spectrogram from an acoustic recorder located inside the nacelle of the CART 3 turbine during an 82 second startup and shutdown sequence.

*Static Tests*

We collected acoustic data during initial impact tests on a stationary blade. Tests included tennis balls hand thrown from the nacelle, as well as those shot from the compressed air cannon on the ground. During static tests the acoustic signal of the compressed air cannon and the impact of the tennis ball were both detectable and about 1 sec apart in the acoustic spectrogram with the microphone located inside the nacelle (Fig. 3.3.1).

*Operational Tests*

We collected acoustic data of turbine operation and impacts from inside and outside the nacelle. The spectrogram from the inside of the CART 3 turbine during startup and shutdown with the generator engaged demonstrated the intense background noise (Fig. 3.3.2) that could mask some impact and bioacoustics signals. Indeed, during impact tests the signal of a tennis ball impacting the blade was not readily detectable with the microphone located inside the nacelle (Fig.3.3.3). With the microphone mounted outside of the nacelle, however, an impact signal was detected (Fig. 3.3.3).

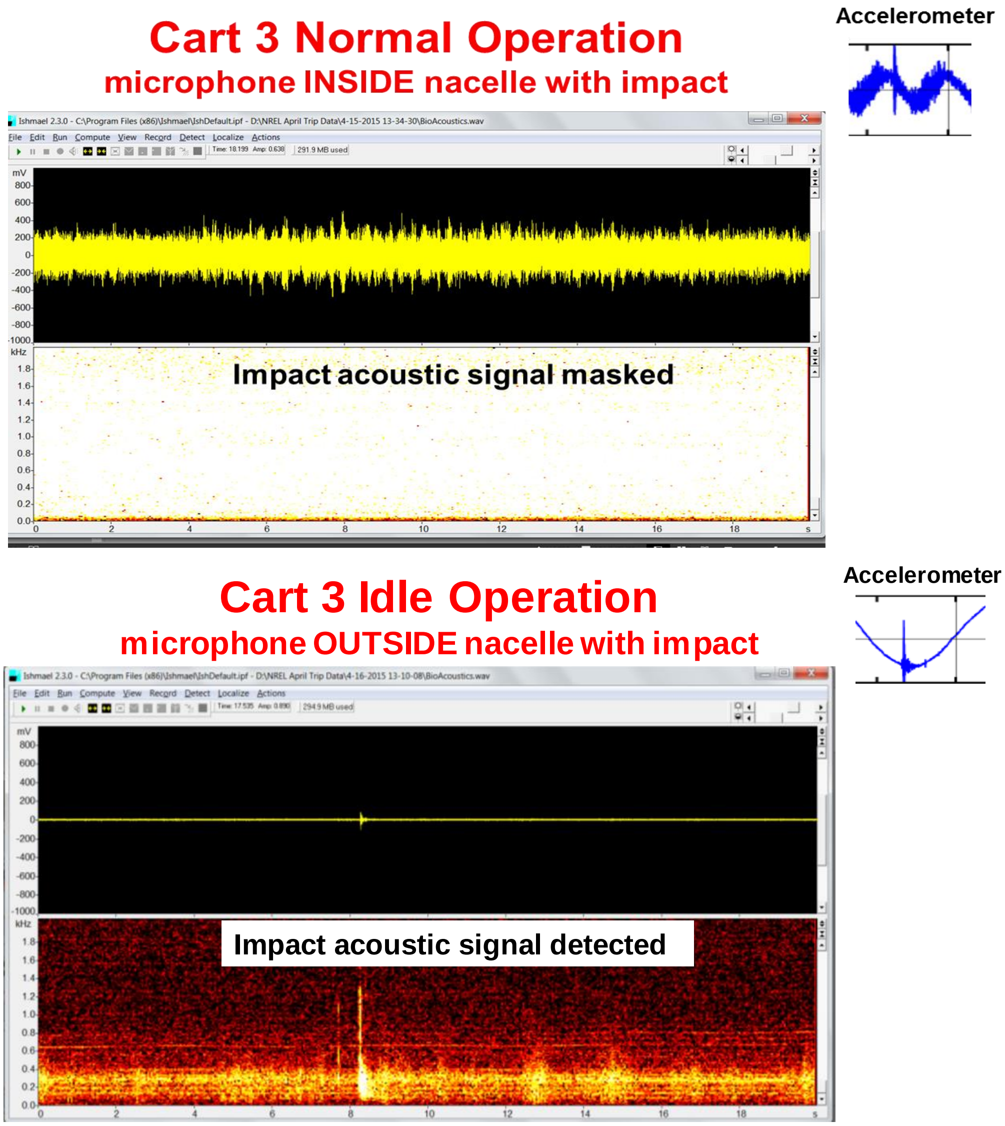



Figure 3.3.3. (top) Spectrogram from an acoustic recorder located inside the nacelle during normal operation of the CART 3 600 kW turbine. A blade impact of a tennis ball shot from the compressed air cannon on the ground was masked by the background operational noise of the turbine. (bottom) Spectrogram from an acoustic recorder located outside the nacelle showing a blade impact of a tennis ball shot from the compressed air cannon on the ground during idle turbine rotation.

### *3.4. System Integration, System Triggering, and Event Detection*

We used National Instruments LabVIEW to write custom programs to operate instruments within each node and to integrate all nodes to record through a single trigger interface (Fig. 3.4.1).

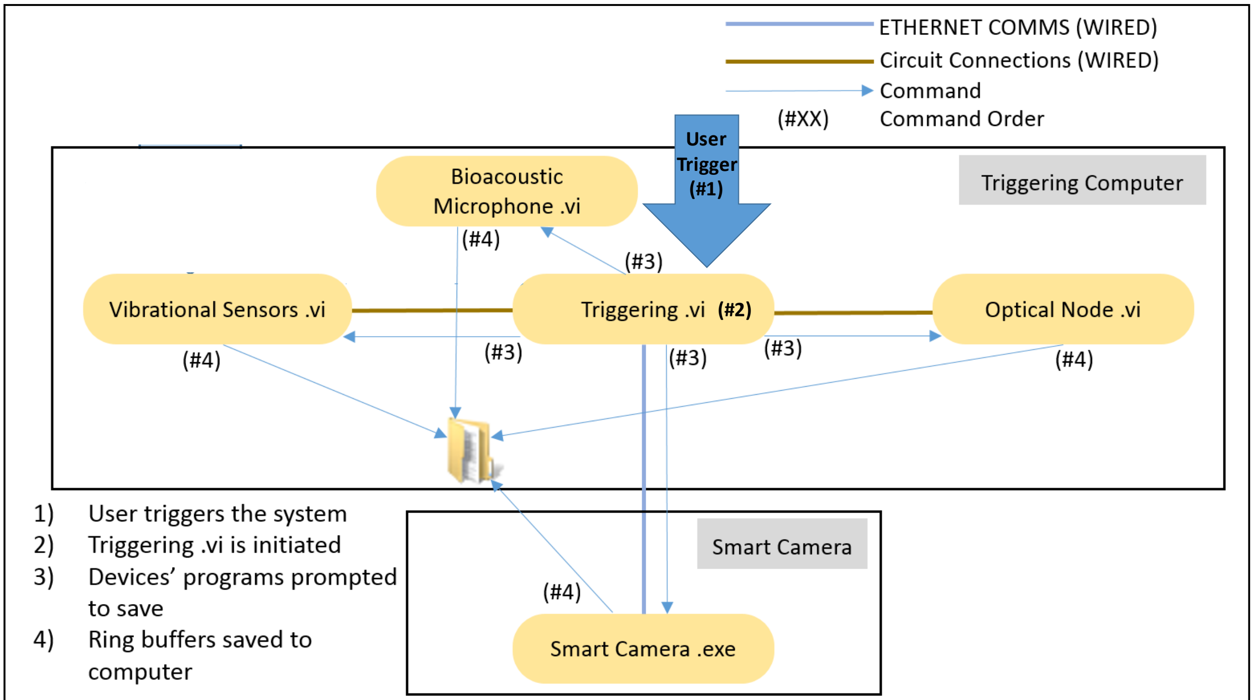



Figure 3.4.1. Schematic diagram of individual LabVIEW programs and communication links between nodes of the sensor array.

*Manual Triggering*

The LabVIEW VI was initially programmed for manual triggering during impact testing. As soon as an impact was observed, manual triggering saved vibration, optical, and bioacoustic node data from the ring buffer for 10 seconds before and after triggering (i.e., total buffer length of 20 seconds). These data were later post-processed to assess impact detection and magnitude of signals. We used manual triggering for all dynamic tests with the turbine in operation.

*Automated Triggering*

As noted above, wavelet analysis showed promise for automated event detection. The preliminary results validate the planned implementation of a wavelet-based event detection algorithm. Using both artificially generated vibrations data and real vibrations measurements, it was possible to find the time of occurrence of a simulated impact at high-level of kinetic energy. Low-energy impact detection requires further investigation. Additional experimental data from laboratory and field tests will be critical for system tuning, implementation and validation (Flowers 2015). Furthermore, we continue to evaluate other event detection algorithms. Use of automated event detection and triggering in real time is feasible, but requires additional development beyond our project.

As a proof of concept for automated triggering, however, we did use a threshold filter on the accelerometer data stream during static blade impact tests, therefore not requiring removal of background signals. After selecting an appropriate threshold, the automatic trigger on static blades was highly successful, with all four impacts successfully triggering the system (Table 3.1.2). This test demonstrated that it is feasible to trigger the sensor array through single impact events sensed by the vibration node, however, a more advanced triggering algorithm will need to be developed.

## 4. Next Generation System Design & Commercialization

### *4.1. Vision Statement*

Wind energy production in the U.S. is projected to increase to 35% of our nation's energy by 2050. This substantial increase in the U.S. is only a portion of the global wind industry growth, as many countries strive to reduce greenhouse gas emissions. A major environmental concern and potential market barrier for expansion of wind energy is bird and bat mortality from collisions with turbines. However, there are no commercially-available, real-time, impact detection system to document mortality events, inform impact risk assessment, or verify whether impact deterrents are working.

Our blade-mounted multi-sensor array can detect impacts and identify the impact source, including small birds and bats, in real-time on operating, commercial scale turbines. Data streams to wind facility operators could allow immediate assessment of impact events. Technology and industry advances over time will allow this low-cost monitoring system to be designed into materials during manufacturing so that all turbines could be monitored with either a subset or full suite of sensors. As standard equipment on all commercial turbines, the industry could effectively monitor whether individual turbines were causing mortalities or not and under what circumstances, as well as evaluating mechanical and structural integrity of a turbine via real-time vibration, image, and acoustic data streams – permitting modification or shut-down to limit environmental or mechanical damage.

### *4.2. System Description*

We envision a commercially viable system will have all vibration, optical, and acoustic sensors integrated in a single unit to attach to the blade of a turbine (Fig. 4.2.1). The sensor unit will be powered by batteries that are charged by solar panels and kinetic blade motion. Smart sensors will permit near-real-time onboard processing of data, thereby reducing the computational burden of the central computer and improving overall system efficiency. Integrated sensor units can be attached to currently operating turbines, but ultimately we anticipate that sensors will be built into blade design and manufacturing.

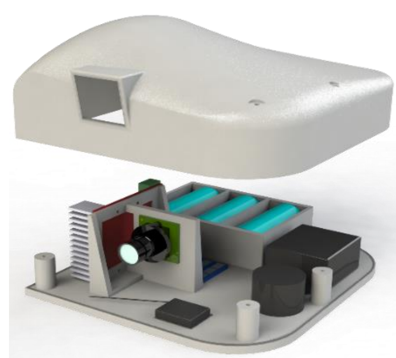


Figure 4.2.1. Integrated sensor array to be mounted on turbine blade. Ultimately, we anticipate that sensors will be built into blade design and manufacturing.

### *4.3. Application*

Once installed, the accelerometers and contact microphones could be used to build a vibration "signature library" for individual turbines, each signature being unique yet temporally variable, which a learning algorithm could adapt to. Over time the sensor array and event detection algorithms could become increasingly more informed to detect subtle impacts beyond standard operational signals. Furthermore, continuous monitoring of the turbine by the sensor array will provide real-time assessment of the structural integrity of the turbine. Turbine operators could also use the vibration, image, and acoustic data streams to detect irregularities, environmental conditions, or unforeseen events that may affect power output, or lead to potential failure before the next scheduled turbine maintenance.

There are numerous ways in which the sensor array could be scaled to meet commercial needs. Initially, the array could be deployed on several turbines at a small-scale evaluation or demonstration site. At a commercial-scale facility, full sensor arrays could be deployed on a subsample of the turbines in strategic, but statistically relevant, locations. The remainder of the turbines could be instrumented with only the vibration node, allowing detection of impacts and structural monitoring of the turbine, but no image or audio data to help identify causes of impacts of operational irregularities of turbine.

### *4.4. Commercialization Plan*

Commercialization of the system could require roughly four major steps (Table 4.4.1). 1) Obtain intellectual property protection for the concept and system design; 2) Obtain additional funding and seek capital investment and partnering with an engineering firm to refine current system design. Conduct additional experimental tests, and extended test deployments on commercially operating turbine in a high impact area; 3) Scale-up system design for commercial deployment; 4) Identify commercialization pathway and creation of division or new company that builds end-user software products or provides fee-based system set-up and life-cycle monitoring.

Table 4.4.1.

| Action | Description | Date Completed |
|---|---|---|
| Step 1: Provisional patent | Oregon State University filed a United States provisional patent application (No. 62313028) for the blade-mounted, integrated sensor array | March 2016 |
| Step 2: Potential Partners and funding | Oregon:<br>• OSU Advantage Accelerator to analyze market, identify customers, examine supply chain to identify the right commercialization partners<br>• University Venture Development Funds to improve prototype<br>• Funding from Oregon BEST (Oregon Built Environment & Sustainable Technologies Center, Inc.) | Before March 2017 |
| | Other States:<br>• California Energy Commission<br>• New York State Energy Research & Development | TBD |
| | Federal:<br>• Department of Energy | TBD |
| | Private:<br>• Renewable Energy Systems Americas, Inc.<br>• NextEra Energy Resources | TBD |
| Step 3: System design for commercial scale use | Possibly license to an existing company or creation of a new venture (decision based on information gathered and results from above tasks) | After March 2017 |
| Step 4: Commercialization pathway | Use information gathered from above tasks to develop a commercialization pathway. | TBD |

# Wind Turbine Sensor Unit for Monitoring of Avian & Bat Collisions

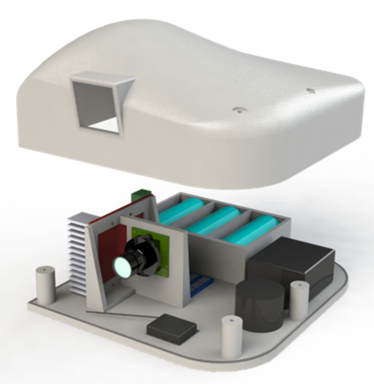
*Wind turbines are a substantial and growing source of renewable electricity. However, the collision of endangered bird and bat species with turbines poses a serious barrier to turbine deployment, both offshore and on land. Standard carcass counting land survey methods are fraught with uncertainty and error, and this method is impossible for offshore turbines. An integrated multi-senor system, capable of providing temporal and spatial coverage of collision events has been developed to monitor collision events to address this need. The invention enables the environmental impacts of wind turbines to be remotely monitored and ensure the benefits of renewable power generation are not outweighed by mortality of protected species.*

Available Technology:

Environment & Sensing

Please Contact:
David Dickson
IP & Licensing Manager
541.737.3450
David.dickson@oregonstate.edu

**Technology Ref. # OSU-15-21**



## TECHNOLOGY DESCRIPTION

An integrated multi-sensor detection package with event-based data collection has been developed using accelerometers, microphones, and a cameras coupled with integrated signal processing. The sensors are installed directly on wind turbine blades and on-board processors wirelessly transmit data to the central controller and data acquisition system immediately after a collision. The accelerometers and contact microphones provide continuous temporal coverage for collision detection. The visual and IR cameras and bioacoustic recorders provide taxonomic classification. Wireless connectivity, low power consumption, and small size allow these sensors to be installed on existing turbines with minimal impact and easily integrated into new turbines.

## STATUS

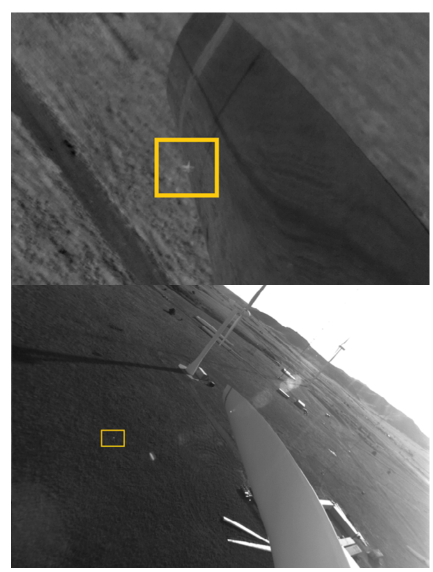
Provisional patent application filed. Seeking commercial development partner, available for licensing.

## Applications

- Bird and bat collision monitoring
- Off-shore and terrestrial turbines
- Species classification

## Features & Benefits

- Low-cost
- Retrofittable on existing turbines
- Easily integrated into new turbines
- Temporal and spatial coverage



Oregon State UNIVERSITY

# About the Principal Investigator

**DR. ROBERTO ALBERTANI**

Dr. Robert Albertani is an associate professor of mechanical engineering at Oregon State University. Dr. Albertani received his MS in aeronautical engineering from the Polytechnic University of Milan, Italy, and a PhD in mechanical & aerospace engineering from the University of Florida.

Dr. Albertani's research interests include aerodynamics and stress analysis of flexible structures, environmental impact of wind energy, high-performance sailboat testing techniques, fiber composites technology, micro air vehicles, and biological flight mechanics.

## 5. Summary of project accomplishments

### *5.1. Patents*

Oregon State University filed a United States provisional patent application (No. 62313028) for the blade-mounted, integrated sensor array, March 2016

### *5.2. Publications & Other Products*

*Proceedings*

Flowers, J., R. Albertani, T. Harrison, B. Polagye, R. Suryan. 2014. Design and initial component tests of an integrated avian and bat collision detection system for offshore wind turbines. Proceedings of the 2nd Annual Marine Energy Technology Symposium, Seattle, WA, April 15-18, 2014. http://vtechworks.lib.vt.edu/bitstream/handle/10919/49197/65-Flowers.pdf?sequence=1

*Thesis*

Flowers, J. M. 2015. Design and testing of an integrated wildlife-wind turbine interactions detection system. M.S. thesis. Oregon State University, Corvallis, Oregon.

*Book chapter*

Henkel, S.K., R.M. Suryan, B.A. Largerquist. 2014. Marine renewable energy and environmental interactions: Baseline assessments of seabirds, marine mammals, sea turtles, and benthic communities on the Oregon shelf. *In* Marine Renewable Energy Technology and Environmental Interactions. M. A. Shields and A.I.L. Payne (Eds.). DOI 10.1007/978-94-017-8002-5. Springer, Dordrecht.

### *5.3. Presentations*

*Invited*

Suryan, R.M. 2015. Assessing potential marine bird impacts from offshore energy development. Oregon State University, Corvallis, Oregon

Suryan, R.M. 2014. A synchronized sensor array for remote monitoring of avian and bat interactions with offshore renewable energy facilities. Department of Energy, wind power peer review. Arlington, Virginia.

Suryan, R.M., R. Albertani, B. Polagye. 2012. A sensor array for remote monitoring of avian and bat interactions with wind turbines. Northwest National Marine Renewable Energy Center annual meeting. Corvallis, Oregon.

*Scientific conference*

Suryan, R.M., R. Albertani, B. Polagye, J. Flowers, T. Harrison, C. Hu, W. Beattie. 2015. Design and Development of an Integrated Avian and Bat Collision Detection System for Wind Turbines. North American Wind Energy Academy, Blacksburg, Virginia

Suryan, R.M., R. Albertani, B. Polagye, J. Flowers, T. Harrison. 2014. Near real-time detection of avian and bat interactions with wind turbines. National Wind Wildlife Research Meeting X, Broomfield, Colorado.

Harrison, T. B. Polagye, R.M. Suryan. 2014. Remote monitoring of birds and bats using visual and infrared stereo imagery. National Wind Wildlife Research Meeting X, Broomfield, Colorado.

Flowers, J., R. Albertani, B. Polagye, R. Suryan, T. Harrison. 2014. Remote monitoring of avian and bat interactions with offshore wind energy facilities. 2nd Annual Marine Energy Technology Symposium, Seattle, Washington.

Suryan, R.M., R. Albertani, B. Polagye, J. Flowers, T. Harrison. 2014. A synchronized sensor array for remote monitoring of avian and bat interactions with offshore wind turbines. Ocean Sciences Meeting, Honolulu, Hawaii.

Suryan, R.M., R. Albertani, B. Polagye. 2012. A synchronized sensor array for remote monitoring of avian and bat interactions with offshore renewable energy facilities. Pacific Seabird Group Annual Meeting, Turtle Bay, Hawaii.

*Public*

Suryan, R.M. 2014. Seabirds and wind energy. Newport Intermediate School 6th grade science classes, Newport, Oregon

Suryan, R.M. 2014. Seabirds and Marine Renewable Energy. Renewable Energy Challenge for high school students, Oregon Sea Grant, Hatfield Marine Science Center, Newport Oregon.

Suryan, R.M. 2014. Seabirds and marine renewable energy off the Oregon coast. Yaquina Birders and Naturalists. Newport, Oregon

Suryan, R.M. 2012. Lost at sea: Monitoring the effects of wind energy devices on seabird mortality. Oregon Sea Grant Career Day, Hatfield Marine Science Center, Oregon State University.

## 5.4. Media

*TV News*

KEZI News, Eugene: *Offshore Wind Turbines May Be Dangerous for Birds, Bats* (2012) http://kezi.com/news/local/239071

*Radio*

OPB: *OSU Gets $600K To Study Wind Power's Effect On Birds, Bats* (2012) http://news.opb.org/article/osu-gets-600k-study-wind-powers-affect-birds-bats/

OPB NEWS

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OSU Gets $600K To Study Wind Power's Affect On Birds, Bats

Oregon State University researchers are going to spend the next three years studying the impact that off-shore wind energy development might have on birds and bats.

OSU's Northwest National Marine Renewable Energy Center announced Tuesday it got $600,000 from the federal Energy Department.

OSU biologist Rob Suryan says the grant will help him and other researchers develop instruments to measure how wind turbines affect birds and bats. Suryan says the instruments will have to tune out flying debris, and really focus on wildlife.

Suryan explained, "That is a challenge to make sure we're not falsely identifying any objects that might be hitting the blades. But also, I think a big concern to me, is that we can detect even the smallest object – the smallest birds, the smallest bats – that might impact the blades."

Suryan is part of a research team working on the instrument array in Corvallis, Newport, and at the University of Washington. He says it's part of a broader effort to site and monitor wind energy facilities – both on land and on water.

The primary testing of the instruments will be on land. But OSU officials say the research will be relevant to off-shore wind development, too.

*Print/Web*

Oregon State University http://oregonstate.edu/ua/ncs/archives/2012/feb/researchers-eye-system-monitoring-offshore-wind-energy-impacts-seabirds-bats

Hatfield Marine Science Center Currents (newsletter) http://blogs.oregonstate.edu/currents/2012/02/14/researchers-to-develop-system-for-monitoring-wind-energy-impacts-on-seabirds-bats/

Portland Tribune: *OSU to study impact of offshore wind turbines on birds* (2012) http://portlandtribune.com/sustainable/story.php?story_id=132924528122429800


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OSU to study impact of offshore wind turbines on birds
Research will deploy sensors to measure blades, identify birds
BY STEVE LAW
The Northwest National Marine Renewable Energy Center, based at Oregon State University, scored a three-year, $600,000 grant to study the impact of off-shore wind towers on seabirds and bats. The grant came from the U.S. Department of Energy.
"Unfortunately, the usual way to document the impact of wind turbines on birds and bats is to collect the carcasses," says Robert Suryan, an OSU seabird expert and principal investigator on the project. "That would be hard to do out in the ocean," Suryan says.
So researchers are devising an array of sensors, including cameras and acoustic devices, to measure variations in blade movement and identify the bird or bat involved.
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Daily Astorian: *OSU Gets $600K To Study Wind Power's Effect On Birds, Bats* (2012) http://www.dailyastorian.com/news/northwest/osu-gets-k-to-study-wind-power-s-affect-on/article_30030d0f-1fe8-578d-866f-07cb442fc7f1.html

The Chronicle, Lewis County, WA: *OSU Gets $600K To Study Wind Power's Effect On Birds, Bats* (2012) http://www.chronline.com/news/northwest/article_2abbbc30-2436-5c57-9351-8cc2a0b67df4.html

Sustainable Business Oregon: *OSU center gets grant to study offshore wind impact on birds* (2012) http://www.sustainablebusinessoregon.com/articles/2012/02/osu-center-gets-grant-to-study.html

The Daily Barometer, Oregon State University Student Media: *OSU pursues project on ocean-based wind turbines* (2012) http://oregonstate.edu/dept/student_affairs/studentmedia/osu-pursues-project-ocean-based-wind-turbines

Quay Country Sun: *Oregon students, faculty using Mesalands turbines for research* http://www.qcsunonline.com/2013/12/10/oregon-students-faculty-using-mesalands-turbines-for-research/

## 6. Acknowledgements

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Bat Conservation International, Floating Power Plant A/S, and Leidos Maritime Solutions. The Northwest National Marine Renewable Energy Center was instrumental in project development.

Table 6.1 Names and affiliations of advisory panel

| Name | Affiliation |
|---|---|
| Dr. Judd Howell | H.T. Harvey and Associates |
| Dr. Sharon Kramer | H.T. Harvey and Associates |
| Dr. Jon Plissner | ABR Environmental Research and Services, inc. |
| Ms. Manuela Huso | U.S. Geological Survey, For. and Range Eco. Sci. Ctr. |
| Dr. Mike Lawson | National Renewable Energy Laboratory |
| Ms. Karin Sinclair | National Renewable Energy Laboratory |
| Mr. Lee Jay Fingersh | National Renewable Energy Laboratory |
| Dr. Cris Hein | Bat Conservation International |
| Dr. Rebecca Holberton | University of Maine |
| Mr. Anders Køhler | Floating Power Plant AS |
| Mr. Craig DeBlanko | Coastal Community Action Project |
| Mr. Jerry Roppe | Iberdrola Renewables |
| Mr. Kevin Banister | Principal Power Inc. |
| Mr. Mark Waller | Bridgeworks Capital |
| Mr. Richard Williams | Leidos Maritime Solutions |
| Ms. Roberta Swift | U.S. Fish and Wildlife Service |
| Ms. Laura Todd | U.S. Fish and Wildlife Service |

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