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Two-dimensional thermal video analysis of offshore bird and bat flight

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ABSTRACT

Thermal infrared video can provide essential information about bird and bat activity for risk assessment studies, but the analysis of recorded video can be time-consuming and may not extract all of the available information. Automated processing makes continuous monitoring over extended periods of time feasible, and maximizes the information provided by video. This is especially important for collecting data in remote locations that are difficult for human observers to access, such as proposed offshore wind turbine sites. We developed new processing algorithms for single camera thermal video that automate the extraction of two-dimensional bird and bat flight tracks, and that characterize the extracted tracks to support animal identification and behavior inference. The algorithms consist of video peak store followed by background masking and perceptual grouping to extract flight tracks. The extracted tracks are automatically quantified in terms that could then be used to infer animal taxonomy and possibly behavior, as described in the companion article from Cullinan, et al. ["Classification of birds and bats using flight tracks." *Ecological Informatics*, 27:55–63]. The developed automated processing was evaluated using six video clips containing a total of 184 flight tracks. The detection rate was 81% and the false positive rate was 17%. In addition to describing the details of the algorithms, we suggest models for interpreting thermal imaging information.

1. Introduction

The risks to birds and bats posed by wind turbines, particularly offshore installations, are not well understood. Point counts by observers do not provide the level of detail and temporal resolution needed to fully characterize animal activity, and offshore locations are challenging to survey. Video recording from surface-mounted or aerial platforms has the potential to provide the required information but human analysis of video is time-consuming and difficult to validate. Automated processing can make continuous, long-term observations using video feasible and cost-effective, thereby providing the required information for accurate risk assessment.

It is difficult, if not impossible, for onsite human observers to quantify animal movement patterns through an area over the course of multiple diurnal-nocturnal cycles and during varying weather conditions. This is especially true for offshore wind turbine sites, which may be located in open ocean up to 50 km offshore, an area with limited accessibility and significant objective danger. Observations are necessary during daylight and also at night because many seabirds are known to actively forage at all times (Suryan et al., 2006), and both landbirds and shorebirds migrate over water at night (Liechiti et al., 1995; Lindeboom et al., 2011). A remote sensing solution can provide continuous coverage over extended periods of time if 1) an appropriate sensor that can capture the required information is used, and 2) the sensor data are efficiently processed in a way that distills the essential information while minimizing data storage and transmission requirements.

Suggested methods for assessing the impact on birds and bats from offshore wind energy development identify the primary risks as collision mortality and habitat loss through displacement (Desholm et al., 2004; Robinson Willmott et al., 2013). Metrics defined to estimate these risks include relative abundance, annual occurrence in hours, migration traffic rate, mean flight altitude, and time spent feeding in the area. At a minimum, animal abundance and passage rates are needed (Kunz et al., 2007). Concern is focused on threatened and endangered species, and on migratory seabirds and passerines. A remote sensing solution will enable accurate passage counts and capture enough information to make inferences about the taxa of observed animals and their behavior.

Thermal infrared video can provide information about animal passage rates and activity patterns during both day and night. Thermal imaging has been used to study nocturnal bird migration traffic (Gauthreaux and Livingston, 2006; Zehnder et al., 2001), bat behavior in terrestrial settings (Betke et al., 2008; Cryan et al., 2014; Hristov et al., 2008), and avian interactions with offshore wind turbines (Desholm et al., 2006). Of all of these studies, only the bat studies used automated processing to count the number of animals; the other studies using thermal imaging relied on manual analysis.

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We have developed algorithms to automatically extract the two-dimensional flight tracks of birds and bats from single camera thermal video. This work was originally inspired by the work of Gauthreaux and Livingston (2006), where a thermal camera, a customized radar system, and a video peak store device were used to record the flight tracks of nocturnally migrating birds.

Automated processing of thermal video was developed by Betke et al. (2007) for censusing bats. The challenge was to track very large numbers of animals in the field of view at the same time. The approach was to use a detection algorithm applied to each video frame to detect objects, combined with a tracking algorithm that tracked the detected objects and an assignment algorithm that assigned detected objects to tracks. The Betke tracking algorithm was sophisticated—and computationally expensive—because it needed to track and count hundreds of individual animals at the same time. Our approach is simpler, less computationally and memory intensive, yet sufficient for tracking tens of animals in the field of view at the same time.

Three-dimensional tracking of bats using stereoscopic methods was demonstrated by Theriault et al. (2010). Three-dimensional flight trajectories provide more information about animal behavior and flight characteristics than two-dimensional tracks, and can be valuable for studying micro-avoidance behaviors around wind turbines. Stereoscopic tracking requires at least two cameras, and the cameras must be calibrated (Theriault et al., 2014). The effective field of view of each camera is reduced to the area of overlap between the two views. Post-processing is required for 3D trajectory reconstruction. The added costs of stereoscopic methods must be considered in the context of study objectives. For obtaining counts and general activity patterns, two-dimensional track analysis is sufficient.

The Thermal Animal Detection System (TADS) developed by Desholm and Bertelsen (2003) was designed to monitor bird collisions with offshore wind turbines. This remote sensing system used a detection threshold to trigger video capture to limit the amount of recorded data to the times when birds were present in the field of view. The trigger was confounded by moving clouds and the reflective surface of the sea, each of which limited the effectiveness of the system. Our detection approach attempts to address these types of environmental noise by using a localized low-pass filter and by constraining detections to objects moving at a minimum rate.

Our objective was to develop automated processing of thermal video to extract useful information about animal activity for risk assessment and monitoring applications. The technical contributions of this work are:

- software that automatically extracts animal flight tracks from thermal video in near real-time and reduces the raw video data to concise flight track information
- the automatic quantitative characterization of flight tracks in the form of summary statistics of animal size, flight speed, and thermal intensity for each track, and
- equations for translating track statistics into physical units using knowledge of the species expected to occur in the area observed with the video.

2. Methods

2.1. Thermal imaging

The basic components of a thermal camera are shown in Fig. 1. A thermal infrared camera works similarly to an optical camera in that a lens focuses energy onto an array of receptors to produce an image. A thermal image is an intensity image, where the intensity value of each pixel is related to the amount of thermal energy incident on an element in the receptor array. A thermal image contains no chromatic (color) information.

The specifications of a thermal imaging camera include the wavelength measured, thermal sensitivity, receptor array size, field of view angles, and the supported frame rates. The specifications for three commercially available cameras are given in Table 1; the leftmost and center columns describe research-grade uncooled cameras and the rightmost column describes a more sensitive cooled camera. Cooled cameras have higher thermal sensitivity than uncooled cameras, and are more expensive to operate and maintain. A shorter wavelength, 3–5 μm, provides better resolution but can be affected by water vapor in the atmosphere. A longer wavelength, 8–12 μm, is more reliable in humid conditions but provides less shape detail. A detailed treatment of atmospheric and metrological effects on thermal imaging can be found on the FLIR webpage (www.flir.com).

The spatial resolution of the camera is determined by the number of receptor elements, which gives the size in pixels of a single frame of video. The field of view, measured in angle degrees, is determined by the focusing lens; some cameras have a zoom capability that provides a range of field of view angles. The spatial area, X by Y meters, of a camera's field of view is

$$X = 2R\tan\frac{\alpha_H}{2}, \quad Y = 2R\tan\frac{\alpha_V}{2}\ \text{meters}, \tag{1}$$

where α_H and α_V are the horizontal and vertical field of view angles, respectively, and R is the range in meters from the camera. A convenient measure of area coverage is the diagonal size of the field of view,

$$D = \sqrt{X^2 + Y^2}\ \text{meters}. \tag{2}$$

The diagonal spatial resolution in pixels per meters is

$$r = \frac{\sqrt{N_H^2 + N_V^2}}{D}\ \text{pixels per meter}. \tag{3}$$

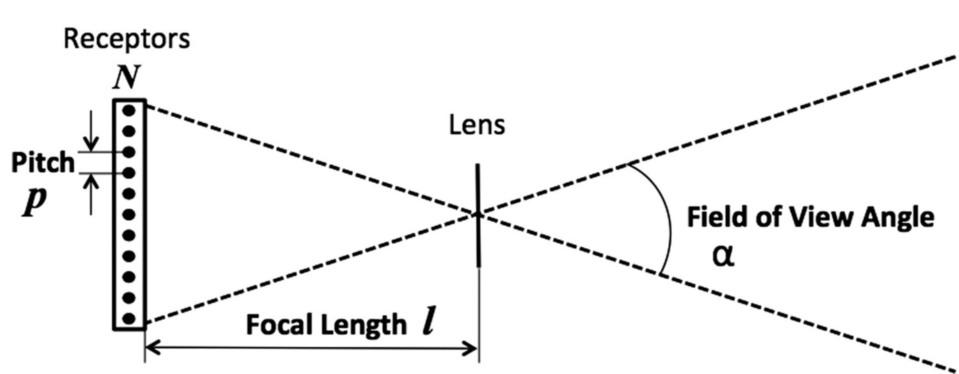

Fig. 1. The thermal imaging camera characteristics that determine the spatial resolution and field of view.