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A Technology Matrix for Bird and Bat Collision Avoidance at Wind Turbines

Fabian Schoden, Jörn Loviscach
FH Bielefeld, Bielefeld, Germany

Summary

Reducing the collision risk for birds and bats at wind turbines is a technologically demanding task. We have surveyed state-of-the-art products and research for bird and bat detection as well as suitable deterrents. To frame this topic, we look at the stakeholders involved and their requirements to be satisfied when using detecting and deterring technology. We examine the suitability of sensors and deterrents in light of these requirements. Furthermore, we point out which technologies require further research to be usable for detecting and deterring in the future. Finally, to look into the promises of artificial intelligence (A.I.) techniques for processing and assessing data from a camera, we have retrained the Google's neural net Inception V3 and are able to detect birds and even classify them automatically.

1. Introduction

Wind turbines pose a significant collision risk to birds and bats [1, 2]. To guide and structure further work by others and by ourselves on reducing this risk, we have systematically built a matrix of requirements (and, hence, engineering problems) and design options (Table 1). Such design options are known from state-of-the-art products and from research; in addition, we discussed potential options not yet implemented. For assessing the viability of these, we use estimates based on data from other domains with related problems and we present our own experiments, for instance, tests with cloud-based services to assess the accuracy of current "deep learning" classification methods to determine a bird's species from a camera picture.

2. Involved Parties

All requirements of the parties illustrated in Figure 1 need to be included in planning a system for the reduction of bird and bat collisions with wind turbines.

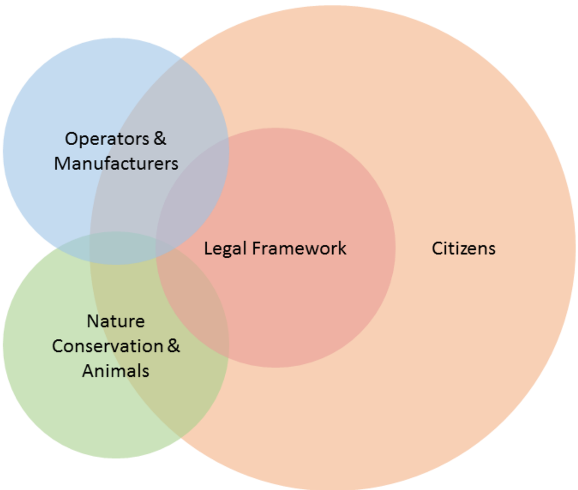

Figure 1: Stakeholders

"Citizens" (without the other listed parties) require a reliable and cheap power supply, quietness and an unspoiled landscape. "Operators & Manufactures" want to maximize their earnings and improve the public's opinion on wind energy. The "Nature Conservation & Animals" disk represents the protection of nature – for instance, landscapes, birds and bats. "Legal Framework" stands for the German laws governing wind energy, citizens' rights and the protection of nature. Essential laws are:

- Bundesnaturschutzgesetz (BNatSchG, Federal Nature Conservation Act) [3]
- Bundes-Immissionsschutzgesetz (BImSchG, Federal Immission Control Act) [4]
- Bundes-Datenschutzgesetz (BDSG, Federal Data Protection Act) [5] and Datenschutz-Grundverordnung (DSGVO, General Data Protection Regulation) [6]

3. Technology Matrix

Table 1 shows a reduced version of our technology matrix of technologies that potentially are feasible for detecting and deterring airborne animals around wind turbines. Important functional requirements that sensors as well as deterrents should satisfy are:

- 300 m of sensor range to be able to react when birds or bats are approaching fast
- 360° surveillance area as animals could approach from any direction
- Operating day and night
- Operating in rain, snow and mist

3.1. Sensors

Lidar technology has insufficient range (120 m, aperture angle of 360°) [7]. Because of the upcoming autonomous cars, the Lidar technology could become cheap and more sophisticated in future [8].

The weather radar system in Europe is suitable for detecting the flight path of flock of birds and bats [9]. Since it is an already existing system, there is no large installation cost to observe the flight path of bird and bat migration and send a shutdown recommendation to wind turbines in the flight path of the animals. Individual radar units, however, are rather cost-intensive – in the order of € 500,000 [10] – but are already used for detecting flocks of birds and bats around wind parks [11, 12]. Since radar is used in aviation and by the military, its technology is advanced and reliable.

A camera with a telephoto lens works during daylight and can detect single birds as well as a flock of birds [13]. The range is considerably shorter than radar: 25 m up to 600 m, depending on bird size [14].

Microphones for detecting bats need to be sensitive to frequencies in the ultrasonic range 20…100 kHz [15]. The spatial range of such sensors is very short and depends on the humidity of the air (60…80 m) [16, 17]. Microphones for detecting birds need to record frequencies from 1 kHz to 10 kHz [18]. Since the frequencies are lower than for bat detection, the spatial range is slightly larger. Birds, however, do not emit as much sound as bats during their flight and therefore cannot be detected reliably by acoustic means.

Infrared Cameras are suitable to detect birds and bats at night. Even though the range is around 20…230 m depending on the animal size [14]. In future, multipurpose cameras may record both at day and at night [19]. A 360° HD camera as well as webcams could be an inexpensive solution, but further investigations in this field are required. Experiments with webcams indicate that the flight path of migrant birds could be tracked by such devices [20]. For this purpose, however, a solution based on the already operational Europe-wide weather radar, which works at day and at night, seems to be closer to realization [9].

Boundary conditions → / Sensors↓	Single bird (1 m wingspann) at day and good weather conditions	Single bird (1 m wingspann) at night	Flock of birds (each bird around 1 m wingspann) and good weather conditions	Single bat at night	Flock of bats at night
Lidar + Hyperspectral					
Weather Radar	accuracy-	accuracy-	night, range+	accuracy-	night, range+
Radar			night, range+		night, range+
(video) Camera + telephoto lenses	accuracy+	night-	accuracy+	night-	night-
Microphone bats	range-	range-	range-	range-	range-
Microphone birds	range-	range-	range-	range-	range-
Infrared camera	day-	night+	day-	night+	night+
360° HD camera					
Deterrents					
Drone	effectivness confirmed		effectivness confirmed		
Chemicals	effectivness-	effectivness-	effectivness-		
Ultrasound 20 kHz - 100 kHz				effectivness confirmed	effectivness confirmed
Loudspeakers 10 Hz - 10 kHz	effectivness confirmed	effectivness confirmed	effectivness confirmed		
Laser	range+	range+	range+		
Magnetic field	effectivness-	effectivness-	effectivness-		
Radar				effectivness confirmed	effectivness confirmed

Suitable — Research necessary — Not suitable

Table 1: Technology Matrix

3.2. Deterrents

Deterring birds with drones is effective; currently, however, drones are steered manually [21] and are subject to a complicated legal framework as a pilot license is required and one is not allowed to fly over someone else's property [22] – hence, autonomous drones may pose legal issues.

Receptacles of approximately 5 cm diameter with specific chemicals are used in urban areas to deter pigeons or seagulls. The effectiveness could not be proven and the range of deterring is too short for this field of application [23].

Ultrasound can be used to deter bats from wind turbines. The range is limited, especially during humid conditions [24]. Birds can be effectively deterred by a laser. Even though this product needs to be controlled manually or just deters in a fixed programmed area [25]. Birds have sensory organs for using the magnetic field of the earth for orientation. That is why a magnetic deterrent could be used to deflect the flightpaths of birds and lead them away from the wind turbine [26]. The effectiveness of existing magnetic deterrents has not been demonstrated yet [27]. Finally, radar can be used to deter bats from wind turbines [28].

4. Problems

In particular, the legal framework could turn out to be problematic. A camera should only observe the sky around the wind turbine not the ground – otherwise personal rights could be violated. With a microphone, sensitive conversations could be recorded accidentally.
Sound or light emitted by deterring devices may annoy neighbors.

Operators of wind turbines need to be convinced to invest in sensors and deterrents. First, they have to buy, install and maintain corresponding devices; second, they probably harvest less wind energy when the wind turbine is choked or shut down for animals; third, quick braking may cause additional strain to the turbine and hence increase maintenance costs or reduce the lifespan.

Interventions such as shutting down the wind turbine may be restricted to periods of high bird and bat activity such as breeding or migration seasons. The choice of the location of the wind turbine [1, 2] may be the most important factor. As one result of employing monitoring systems at wind turbines, information about animal population in specific regions can be extracted from the recorded data. Consequently, regions with high animal activity could be avoided for future wind energy projects.

5. Machine Learning

To look into the potential of A.I. technology, we studied how to automatically classify sensor data using machine learning. A straightforward way to apply machine learning is to use the Google Vision API [29]. This machine learning algorithm is able to detect birds with a pretty high accuracy and can even classify single birds, see Figure 2.

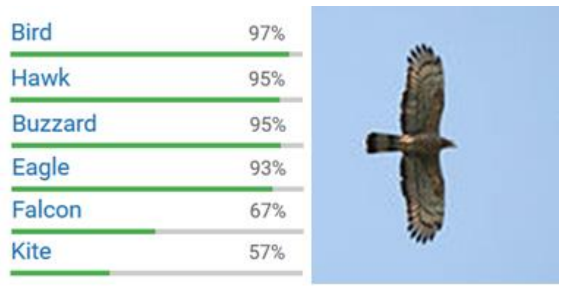

Figure 2: The result of Google's Vision API [29] for an image of a buzzard [30]

To raise the accuracy even further, we employed an already trained algorithm from Google – namely, Inception V3 [31] – and retrained, as an application of transfer learning, its ultimate layer before the output [32]. We used images of crows (721), kites (460) and buzzards (325) from Imagenet [30] as examples. This experiment applied 4.000 training steps, 10 images per step and a learning rate of 0.01. The final results were:

- Training accuracy = 97.0 %
- Cross entropy = 0.10
- Validation accuracy = 83.0 %
- Final test accuracy = 96.9 %

This trained algorithm may be used on an individual computer or may be executed in the "cloud" for real-time classification of the three species we used for training. To improve the accuracy, data should be gathered at the actual location of the wind turbine, taking into account the local weather as well as the local animals and their flight paths.

6. Outlook

In the future, interdisciplinary cooperation between the stakeholders mentioned in Section 2 will be necessary to develop effective and affordable systems for the reduction of bird and bat fatalities at wind turbines. Furthermore, the development of improved and/or novel sensors could reduce the cost of devices and enhance their accuracy. Lidar seems to be a particularly promising candidate due to its application in autonomous cars and for wind speed measurements at wind turbines. The more labelled data are gathered, the more accurate a machine learning algorithm can become. That way, less noise or light pollution is caused for deterring purposes and the downtimes for wind turbines are reduced to a minimum.

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