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A low cost way for assessing bird risk hazards in power lines: Fixed-wing small unmanned aircraft systems

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Abstract: Accidents on power lines are one of the most important causes of man-induced mortality for raptors and soaring birds. The factors that condition the hazard have been extensively studied, and currently there are a variety of technical solutions available to mitigate the risk. Most of the resources in conservation projects to reduce avian mortality now are invested in fieldwork to monitor the lines, which diverts the resources available to install actual corrective measures to mitigate bird hazard. Little progress has been achieved in the methodology to characterize line risk, which is an expensive, tedious, and timeconsuming task. In this work we describe the use of low cost small unmanned aircraft systems (sUAS) equipped with on-board cameras for power line surveillance. As a case study, we characterized four power lines, geo-referenced every pylon in selected portions, and assessed their hazard for birds. We compare the effectiveness of two variants of the sUAS method for data acquisition and two methods of plane control. This work provides evidence of the usefulness of sUAS as a fast, inexpensive, and practical tool in conservation biology, adding to their already known applications in wildlife monitoring, the environmental impact assessment of infrastructures.

Key words: power lines, bird electrocution, environmental impact of infrastructures, fixed-wing sUAS, remotely piloted aircraft, drones.

Introduction

Bird mortality on power lines is an important conservation issue recognized decades ago (Olendorff et al. 1981; Crivelli et al. 1988; Ferrer and de la Riva 1991). Raptor and large bird species are especially prone to electrocution, mostly on distribution lines (Negro and Ferrer 1995), and collision with cables is more frequent on transmission lines, affecting gregarious species or birds that fly at times with reduced visibility (Negro 1987; Ferrer and Negro 1992; Ferrer and Janss 1999).

The distribution of bird accidents on power lines has a significant tendency to accumulate on certain pylons or spans (cable length between two pylons) (Ferrer and Hiraldo 1991; Clave 1992). Thus, by effectively correcting a small fraction of all pylons and (or) spans of a given line it is possible to reduce total mortality drastically (Ferrer and Hiraldo 1991; López-López et al. 2011).

Bird nesting on pylons is another situation that may increase electrocution risk and also produces damage to the infrastructure; both result in economic losses and reduce service quality for utility companies (Red Eléctrica 2005; Ferrer 2012).

Currently, the bulk of the effort in terms of time and costs to mitigate the power line hazard to birds is invested in fieldwork for the characterization phase of the study. Line monitoring is normally done by car or on foot (Katrasnik et al. 2008), identifying pylon design, recording pylon location with a GPS, identifying bird mortalities, and surveying habitat types, all factors that would contribute to the assignment of risk values (Ferrer and Hiraldo 1991).

There are other possibilities for power line study, such as using conventional aircraft with automatic video surveillance systems (Whitworth et al. 2001; Ma and Chen 2004), satellite images, rotary-wing unmanned aircraft systems (UAS) (Campoy et al. 2001; Peungsungwal et al. 2001; Ma and Chen 2004; Jones et al. 2005; Katrasnik et al. 2008; Li and Ruan 2010), and more sophisticated solutions, including climbing-flying robots (Katrasnik et al. 2008), but they are too expensive to be applied routinely in conservation biology studies or they have not been implemented realistically in the field yet.

Fixed-wing small unmanned aircraft systems (sUAS) are undergoing remarkable development, which has led to a decrease in prices and a greater variety of equipment available. Their use has

increased considerably for different purposes in military and civil applications. sUAS have been recently incorporated into wildlife conservation, mainly focusing on aerial wildlife surveys and habitat studies (Jones et al. 2006; Pereira et al. 2009; Watts et al. 2010; Chabot and Bird 2012; Rodríguez et al. 2012; Sardà-Palomera et al. 2012; Getzin et al. 2012).

Here we describe the use of fixed-wing sUAS technology as a tool to characterize power lines to subsequently assess their impact on birds in a low cost way. We also compare the usefulness of two different types of cameras to identify and geo-reference power pylons as well as testing two alternative variants of plane control.

Materials and methods

Study area

Fieldwork was conducted in two locations in southwestern Spain: an agricultural area in Dos Hermanas, Seville (5°56'16.1816"W, 37°15'22.462"N) and a preserved area within Doñana National Park, Huelva (6°31'58.8522"W, 37°6'53.2887"N). Surveys took place in March, April, and December 2012.

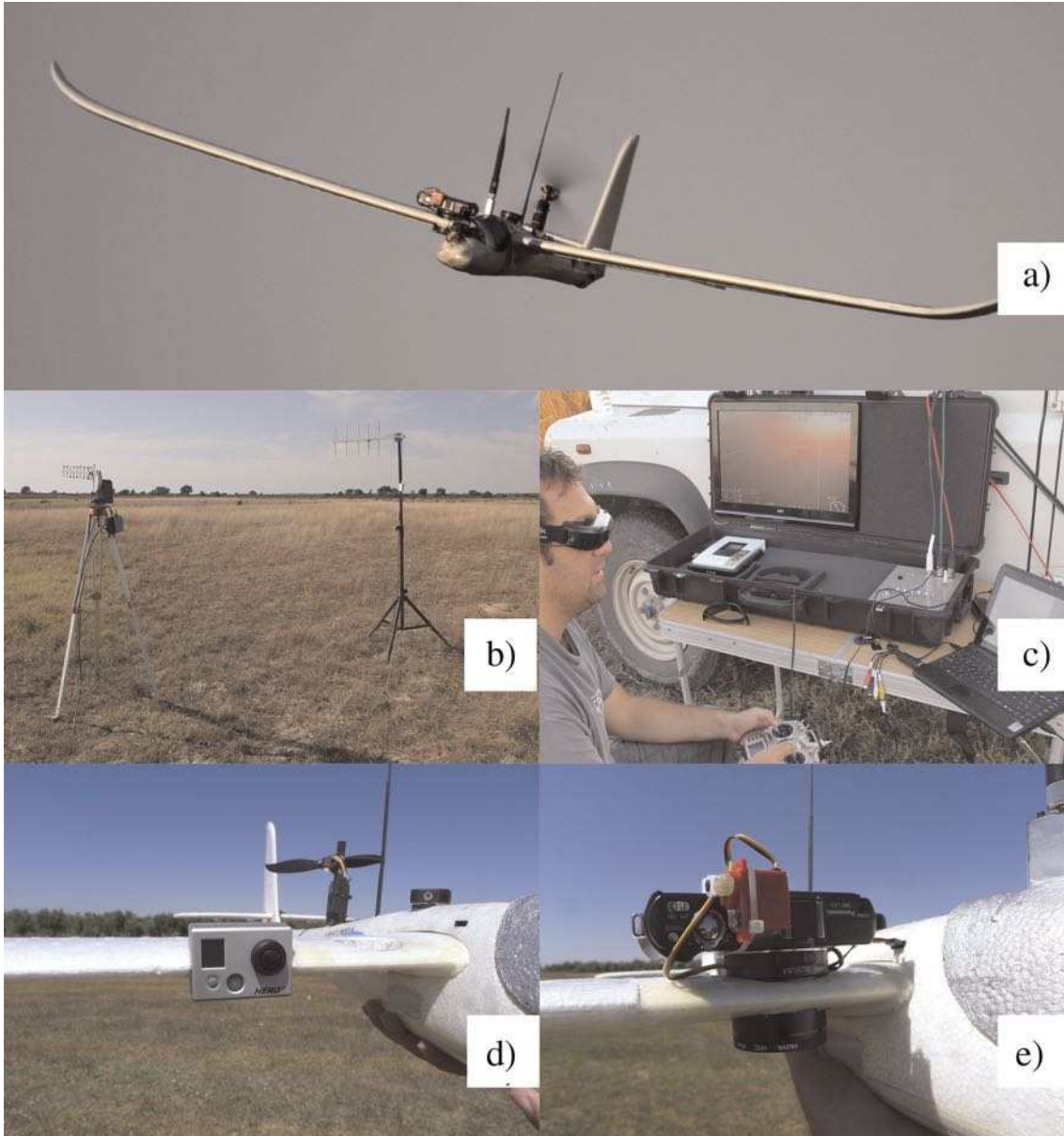
sUAS technical specifications

We used the radio controlled Easy fly St-330 (St-models, China) propelled by a brushless electrical motor. Wingspan is 1.960 m and it has a maximum take-off weight of 2 kg with a 250 g payload (Fig. 1a). Its maximum range is 10 km, endurance 50 min and it can take off and land manually in small patches of flat and open terrain.

Operations can be carried out in two different ways and it is possible to switch from one to the other during the flight.

Automatic mode: the plane is controlled and guided by the autopilot system. No intervention from the pilot is required during the flight (only taking-off and landing are performed manually). The autopilot provides flight stabilization and the capability to program waypoints, and if the control signal is lost, the autopilot activates the "return home" mode.

Fig. 1. Description of our small unmanned aerial system: (a) aerial platform, (b) antennas, (c) ground control station, (d) wing-mounted forward-pointing camera, and (e) wing-mounted nadir-pointing camera.



First person view (FPV) system: the pilot controls the plane in real time using virtual reality glasses and sees telemetry data superimposed on the video. The FPV system includes a long-range radio control receiver.

In both control modes, on-screen display function provides real time flight information (course, altitude, speed, waypoints, and artificial horizon) superimposed on the video signal from a camera located on the plane's nose, which can be visualized on the ground control station. Thus, the operators always have real-time information of the area overflown.

Payload

The sUAS is equipped with two different photo cameras (each one of them mounted on a different flight, but not concurrently): a GoPro Hero 2, 11 MP (Woodman Labs., Calif.) forward-pointing, and a Panasonic LX3, 11MP (Osaka, Japan) nadir-pointing, both programmed to take 1 picture/s (see Figs. 1d and 1e). We also included an Eagletree GPS, V.4 data logger (Eagletree systems, Wash.), which provides accurate tracks of the plane (1 data/s) and includes a barometric altimeter that is used to geo-reference the pictures.

Ground control station

The ground station includes: a flight case, a video tracking system, and a long-range radio control transmitter (Fig. 1c). The flight case contains the equipment needed to visualize the real time video from the plane: a TV monitor, virtual reality goggles, a DVD video recorder, and a laptop that uses the data received with the video to track the UAS on a Microsoft (Redmond, Wash.) map.

The video tracking system integrates a high gain antenna, a motorized tracking system and a 1.2 GHz video receiver (Fig. 1b). Plane control signals are generated by a commercial radio control transmitter (WFT09, WFly, Shenzhen, China). The long range radio control system transmits this signal in

the 434 MHz band using a high gain antenna. The signal emitted is digital and has a frequency hopping system that makes it very difficult to jam and the power output can be selected in the range of 0.5–2W. The approximate cost of the sUAS and its payload was 1800 €, and the ground control station (including antennas) was about 6000 €, as of June 2012.

Data gathering

We performed a total of 13 flights at an altitude ranging from 20 to 50 m above ground level, at an average speed of 30 km/h. Ten flights were done in FPV mode and the remaining three using the autopilot. Seven of the flights were performed with the nadir-pointing camera and the remaining six with the forward-pointing camera. We overflew four power lines (one 60 kV transmission and three 15 kV distribution lines), photographing a total of 122 pylons and their respective spans. We characterized the pylons and evaluated their hazard using the criteria proposed by Clave (1992). We studied them independently by using images obtained from the ground as a control, from the forward pointing sUAS camera, and from the nadir pointing UAS camera. Ground-truth data were obtained by walking along the lines recording the coordinates with a handheld GPS (Garmin Etrex Legend HCx) and photographing the pylons from their base. Images obtained by the nadir-pointing camera had a horizontal view, so they could be superimposed on the map. Images were geo-referenced using a customized extension of ENVI software (Boulder, Colo.) that synchronizes the track of the plane with image time stamps. It considered barometric altitude and the course of the UAS, and generated a “.tiff” file that could be projected onto a map. The coordinates of each pylon were obtained by marking its representation on the geo-referenced image. The forward-mounted camera presented an oblique view, precluding superimposition on a map. The camera had a fisheye lens (a viewing angle of 165° horizontal and 160° vertical). When the top of the pylon appeared in the lower third of the picture, it was estimated that it was below the sUAS, so we considered the sUAS location at the exact time of the picture (registered in the time stamp of the file) to be the pylon location.

Using ground GPS data as a control, we measured the differences between the coordinates obtained with the sUAS flights using Microsoft Excel Version 14.3.1.

To test the repeatability of each camera method we overflew the same pylons twice in FPV mode with each camera method. The results of pylon locations in the four flights were compared under similar weather conditions.

To check the differences between the two plane control methods (autopilot versus FPV) we compared the deviation from the power line trajectory in the two flights made per mode. The differences between the plane trajectories in relation to the programmed routes were calculated using the NEAR tool of Arc GIS 9.3 (ESRI, Redlands, Calif.).

This study was conducted in accordance with EC Directive 86/609/EEC for animal handling and experiments, and with the current Spanish legislation involving aviation safety. Field technicians had the required licenses to operate in the frequencies used for this work. Doñana National Park authorities (Junta de Andalucía) approved permits to conduct this study.










Results

A total of 17 different pylon designs were identified among the 122 pylons that we surveyed (see Fig. 2; see also Fig. 3 for examples obtained by the two airborne cameras, and supplementary material

Fig. 2. Surveyed power lines with pylons geo-referenced by three different methods: (a) Dos Hermanas area, (b) Doñana area. Circle, from GPS at the base of the pylon; square, from sUAS using nadir-pointing camera; triangle, from sUAS using forward-pointing camera.



Fig. 3. Example of pylon designs recorded from the UAS (pylon designs classified following Clave 1992).

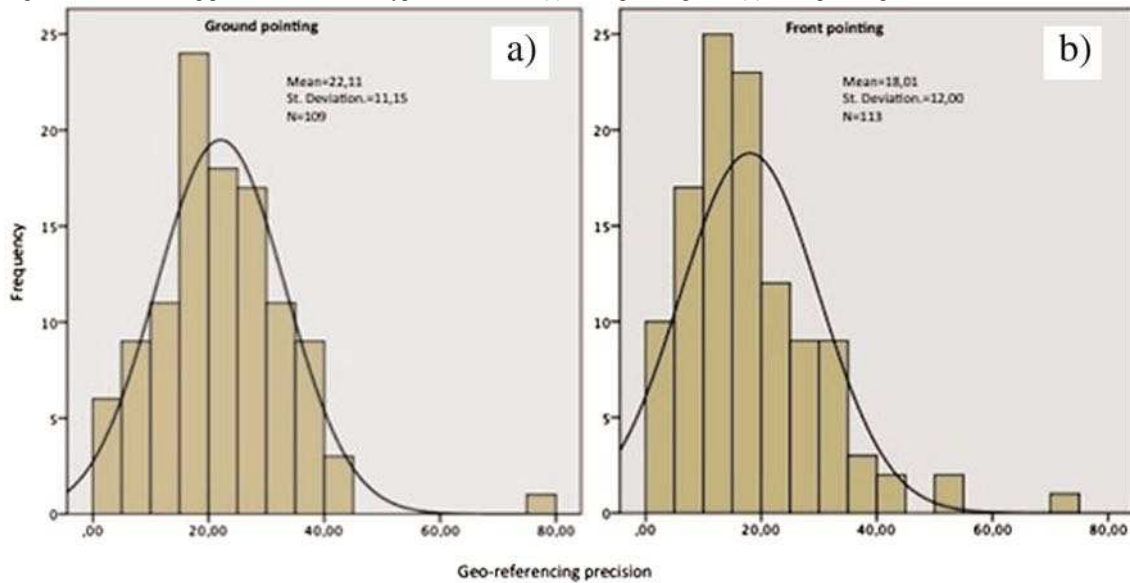
Pylon design	Ground	Front pointing camera	Ground pointing camera
Vaulted configuration with suspended insulators			
Pylons with strain insulators and jumper wires below insulators			
Triple-conductor circuit-breaker on pylon mast			

for a complete catalogue of all designs). Resolution of the images at 50 m above ground level of the nadir-pointing camera was 4.32 cm², and for the forward pointing camera was 8.72 cm². More than 50% of the pylons surveyed presented high electrocution hazard and 95% of the spans had a moderate collision risk for birds (see Table 1). Geo-referencing precision was significantly higher using the forward-pointing camera (mean = 18.01 m, sd = 12.00 m, n = 113) compared to the nadir-pointing camera (mean = 22.11 m, sd = 11.15 m,

Table 1. Evaluation of the electrocution and collision hazard for birds of the pylons and spans surveyed.

Electrocution or collision hazard	Number of pylons (%)	Number of spans (%)
Very low	6 (4.9)	0 (0)
Low	23 (18.9)	6 (4.9)
Moderate	14 (11.5)	116 (95.1)
High	63 (51.7)	0 (0)
Very high	16 (13.1)	0 (0)

Fig. 4. Geo-referencing precision of the two types of cameras: (a) nadir-pointing; and (b) front-pointing.



n = 109; Student's t-test for paired samples = 3.70, $p < 0.05$; Fig. 4). In both cases, the mean error was lower than the interpylon distances (50 m for distribution lines and 100 m for transmission lines). In addition, as the observer knew the direction of the flights, it was not possible to confound one pylon with the adjacent one.

The repeatability of the forward-pointing camera (mean = 11.1 m, sd = 8.2, n = 17) was not significantly different (Student's t-test for paired samples = 0.10, $p = 0.92$) than the nadir-pointing camera method (mean = 10.3 m, sd = 6.0, n = 14).

There were significant differences (Kruskal–Wallis test, $H = 100.86$, $df = 3$, $p < 0.05$) between the deviation from the power line trajectory in relation to the programmed routes in the four flights analyzed. The two flights made with FPV were, however, not significantly different (Mann Whitney U test, $U = 116.9$, $p = 0.99$), whereas the two flights using autopilot differed significantly from each other ($U = 200.7$, $p < 0.05$).

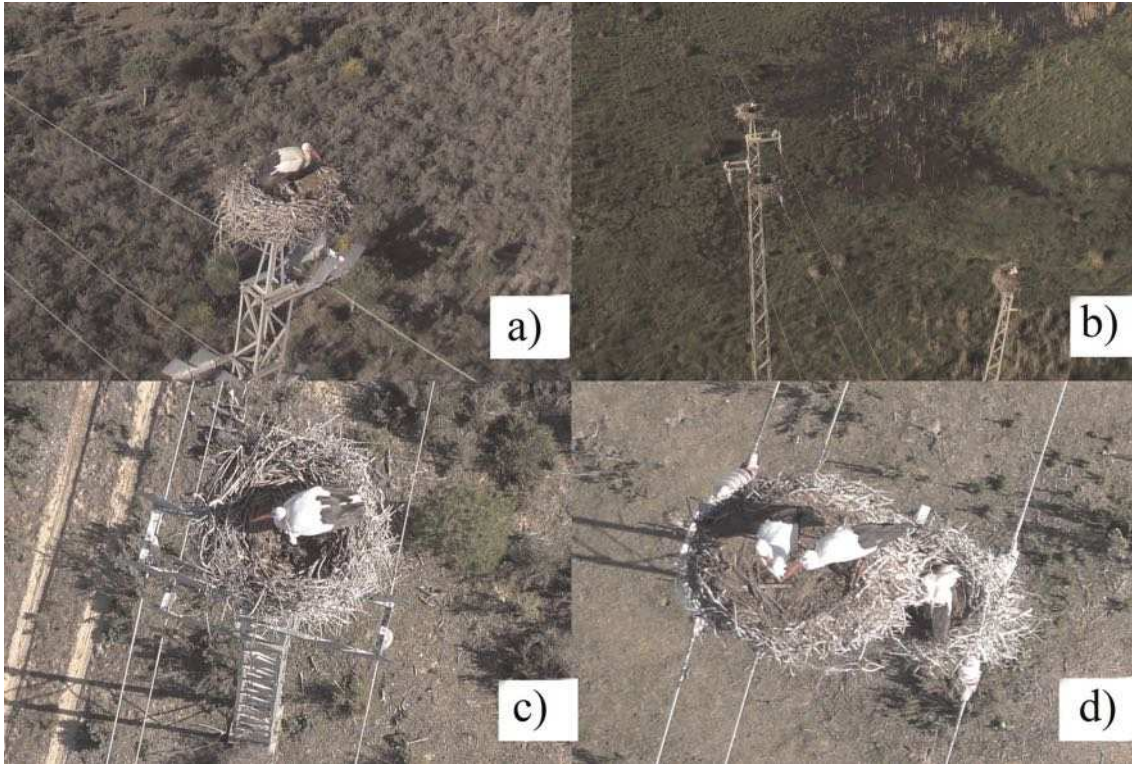
The images obtained with both cameras clearly visualized white storks (*Ciconia ciconia*) both adults and nestlings, and 10 nests on the pylons (Fig. 5). The size and position of the nests revealed high electrocution risk for the birds and for the power line to be damaged by fallen branches.

Discussion

To assess the use of sUAS for power line monitoring, we performed a case study and overflew four power lines, identifying and locating the pylons and assessing their hazards to birds.

We tested two cameras embarked in the sUAS, forward- and nadir-pointing. Both offered pictures with enough resolution to characterize different types of pylons, to detect corrective devices installed, and to inspect bird nests built on them, although the nadir-pointing camera offered the best quality images.

Fig. 5. White stork nests on the pylons: (a) and (b) recorded by forward-pointing camera; (c) and (d) recorded by nadir-pointing camera.



More than half of the pylons presented high electrocution hazard and the majority of the spans presented a moderate collision hazard for birds. The nests on the pylons presented high electrocution risk for the birds and for the power line to get damaged by the material of the nests.

The UAS methodology provided valid geo-referencing precision for each pylon. The forwardpointing camera technique was more precise than the nadir-pointing one.

We tested two flight control methods: autopilot and FPV, and both acceptably tracked the power line. Nonetheless, the FPV mode adjusted better to the line. For this reason, and keeping low cost as a priority, we consider that it is more convenient to perform low altitude flights in FPV, with the plane operated by an experienced technician. Any drag can produce a deviation out of the track that will result in blurred pictures; it would reduce the precision of the geo-referencing or even a collision against the wires, with the consequent danger for both the plane and the power line. It is critical to fly in good meteorological conditions with the least possible wind (speed below 20 km/h) to minimize those risks. The autopilots market is improving and the prices are descending fast, so we foresee that autopilot results could be improved while maintaining costs in the near future (Rodríguez et al. 2012). sUAS have proved to be useful to study the design of power pylons and habitat types, the main goals for a typical bird hazard assessment. More information, such as bird density estimates or the presence of sensitive species in the area also would be helpful to make a more complete hazard evaluation of the lines (Ferrer and de la Riva 1991; Ferrer and Janss 1999). Mortality surveys, which are also useful for hazard assignment, may be feasible by using sUAS, at least in open habitats and if conspicuous species are affected, or if the casualties are still hanging from the pylons or wires.

The main objective of our work was to develop a method that balances the cost, practicality, quality, and effectiveness for bird hazard studies in power lines. There are more sophisticated sUAS available in the market that can fly longer distances, cameras that provide higher resolution images, and software to automate line monitoring (Li and Ruan 2010). Additionally, the use of thermal cameras would also allow the identification of problematic points for operation conditions of the power lines, increasing the benefits of this approach for utility companies (Bologna et al. 2002; Han et al. 2009; Stolper et al. 2009). Any improvement in those characteristics would imply an increase in the overall costs, which is what we wanted to minimize, as the main objective for bird conservation is to invest resources on pylon modification and not in fieldwork.

Table 2. Comparison of methods for power lines surveillance.

Method	Costs	Quality of the data for pylons' study	Availability and logistics	Other factors
Commercial satellite images	High	Low	Made to order.	Clouds can preclude images obtaining.
Conventional aircraft	High	High (depending on flying altitude and sensors quality)	Conditioned to favorable weather and proximity to an airstrip.	Need of specialized personnel; risk for the plane crew.
Survey by foot or car	Medium	Very high	Conditioned to the accessibility and ownership of the area; time consuming.	Bureaucratic process to access the farms.
Robots	High	Very high	Time consuming; requires a lot of advance planning.	Not implemented realistically yet.
sUAS	Low	High (depending on flying altitude and sensors quality)	Immediate data collection; conditioned to favorable weather and landowner permission.	Need of specialized personnel; limited to UAS range.

The knowledge and skills needed for the correct and safe operation of sUAS is also of paramount importance. Most of the manufacturers would describe their planes as “user-friendly”, and that is true in the sense that it is not necessary to be a qualified pilot to use them. But, “remote control skills are needed for piloting, some knowledge is needed for maintenance and supervising, and even basic tasks as take offs can demand a certain level of athleticism from the operators” (Jones 2003). sUAS offer advantages over other power line surveillance techniques (see Table 2 for a summary). Conventional aircrafts with automatic video surveillance systems (Whitworth et al. 2001; Ma and Chen 2004) provide high resolution images and can cover much more ground, but their use presents important drawbacks, such as the risk for the crew and the need of an airfield in the proximity for take off and landing, that do not apply when using sUAS.

In recent years there have been significant advances in the field of robotic automation that led to imaginative solutions for power line inspection (Katrašnik et al. 2008). Although this is a promising line of work, their use has not been implemented realistically in the field and their cost is high, sUAS being less expensive and more immediately available.

In the framework of UAS, rotary-wing platforms have been chosen for most of the engineering projects aimed at supporting utility companies that need high detail of wires' conditions (Campoy et al. 2001; Peungsungwal et al. 2001; Ma and Chen 2004; Jones et al. 2005; Katrasnik et al. 2008; Li and Ruan 2010), because their ability to hover offers more stability than fixed-wing ones for taking high-resolution pictures. It is important to note, however, that wildlife managers do not tend to need such a level of detail for bird hazard assessment. The resolution provided by the commercial cameras of the types we used in our study is enough, and fixed-wing sUAS offer other advantages, such as higher range and autonomy, ease of piloting, and, in the event of a malfunction or a crash, they are usually cheaper to repair than rotary-wing ones (see Table 2).

The effort and cost to characterize power lines in terms of bird protection largely depends on the extent and accessibility of the network and revision schedules, which vary according to environmental conditions and the durability of the materials employed. Line surveying costs are, however, significant. As an example, Ergon Energy, from Australia, declares expenditures of \$80 million a year on inspection (Li and Ruan 2010). In the Andalusia region (Spain), approximately 20% of the total budget spent in retrofitting dangerous distribution power poles to protect the endangered Spanish imperial eagle (*Aquila adalberti*) was the cost for identification of power pole design, which was around 500 000 € (López-López et al. 2011). It is important to point out that this kind of surveillance of the poles is necessary not only during pole characterization prior to selecting which ones must be modified, but also a periodic survey of antielectrocution devices is needed. Limited lifespan of insulation protective devices requires periodic inspections to assure effective protection. Similarly, large bird nests on power poles require periodic surveys to prevent outages. Consequently, reduction in the total cost and time using sUAS would be greater.

As a reference, for the sUAS inspection of the 12 km of lines surveyed for this study, four flights were needed. On each one of them, the two operators invested a total of 2 h for the sUAS preparation, flight, and data processing.

Our study is the first one demonstrating that low-cost fixed-wing sUAS are a useful tool for power line monitoring and offer advantages in cost and time investment versus other methods. Our system, valued at 7800 €, has been able to geo-reference and characterize power lines providing the information needed to assess bird electrocution and collision hazard. Thus, their use can help to minimize the resources invested in the fieldwork phase of the work, to allocate most of the funds into actual corrective

measures.

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