Conservation Letter

Dawn of drone ecology: low-cost autonomous aerial vehicles for conservation

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Abstract

Tropical deforestation continues to be a major driver of biodiversity loss and greenhouse gas emissions. Remote sensing technology is increasingly used to assess changes in forest cover, species distributions and carbon stocks. However, satellite and airborne sensors can be prohibitively costly and inaccessible for researchers in developing countries. Here, we describe the development and use of an inexpensive (<$2,000) unmanned aerial vehicle for surveying and mapping forests and biodiversity (referred to as 'Conservation Drone' hereafter). Our prototype drone is able to fly pre-programmed missions autonomously for a total flight time of ~25 minutes and over a distance of ~15 km. Non-technical operators can program each mission by defining waypoints along a flight path using an open-source software. This drone can record videos at up to 1080 pixel resolution (high definition), and acquire aerial photographs of <10 cm pixel resolution. Aerial photographs can be stitched together to produce real-time geo-referenced land use/cover maps of surveyed areas. We evaluate the performance of this prototype Conservation Drone based on a series of test flights in Aras Napal, Sumatra, Indonesia. We discuss the further development of Conservation Drone 2.0, which will have a bigger payload and longer range. Initial tests suggest a flight time of ~50 minutes and a range of ~25 km. Finally, we highlight the potential of this system for environmental and conservation applications, which include near real-time mapping of local land cover, monitoring of illegal forest activities, and surveying of large animal species.

Keywords: Species extinction, orangutan, spatial analysis, logging, poaching

Received: 14 April 2012; Accepted: 20 April 2012; Published: 9 July 2012.

Cite this paper as: Koh, L. P. And Wich, S. A. 2012. Dawn of drone ecology: low-cost autonomous aerial vehicles for conservation. *Tropical Conservation Science* Vol. 5(2):121-132. Available online: www.tropicalconservationscience.org

Introduction

Tropical deforestation is a major contributor to greenhouse gas emissions and biodiversity loss [1]. In Southeast Asia, for example, forest conversion to plantations of oil palm, rubber, cacao, and *Acacia* spp. (for pulp and paper) has resulted in deforestation and forest degradation [e.g., ref. 2]. These rapid and widespread land-use changes have severely affected tropical biodiversity [3, 4]. As global demands for food and biofuels continue to place increasing pressures on land in the tropics, an urgent challenge for conservationists is to be able to accurately assess and monitor changes in forest cover, species distributions and population dynamics.

Most conservation researchers and practitioners currently rely on satellite-based remote sensing for mapping and monitoring land use change [5]. However, remote sensing technology might not be accessible for many developing-country researchers due to financial constraints. Although certain low-resolution satellite images are freely available (e.g., Landsat [landsat.gsfc.nasa.gov] and MODIS [modis.gsfc.nasa.gov]), other sub-meter resolution images can be prohibitively costly (e.g., QuickBird [digitalglobe.com], IKONOS [geoeye.com]). Yet, such high-resolution data are often critical for accurately detecting and tracking land use change at the landscape scale (< 1,000 ha). Furthermore, much of the humid tropics is often obscured from remote sensing satellites due to a persistent cloud cover [6]. As such, cloud-free satellite images for a specific time period and location are often not readily available. Researchers typically have to search from a time series of images to obtain the cloud-free data they require, thus rendering any real-time monitoring of land-use change practically impossible.

The second major conservation challenge concerns assessment and monitoring of biodiversity. Currently, this is largely achieved through ground surveys, which can be time-consuming, financially expensive, and logistically challenging in remote areas [7]. For example, ground surveys of orangutan populations (*Pongo* spp.) in Sumatra, Indonesia can cost up to ~$250,000 for a two-year survey cycle. Due to this high cost, surveys are not conducted at the frequency required for proper analysis and monitoring of population trends [8]. Furthermore, some remote tropical forests have never been surveyed for biodiversity due to difficult and inaccessible terrain [9].

To address these challenges, we are developing the use of inexpensive (<$2,000), autonomous unmanned aerial vehicles for surveying and mapping forests and biodiversity (referred to as 'Conservation Drone' hereafter; conservationdrones.org). We describe the development of a prototype drone (Fig. 1) and evaluate its performance based on a series of test flights in Aras Napal, Sumatra, Indonesia. Additionally, we discuss the potential of this system for environmental and conservation applications, which include near-real time mapping of local land cover, monitoring of illegal forest activities (e.g., logging, fires), and surveying of large animal species (e.g., orangutan, elephant, cheetah).

Methods

Drone development and operation

The autopilot system of the Conservation Drone is based on the 'ArduPilot Mega' (APM), which has been developed by an online community (diydrones.com). The APM includes a computer processor, geographic positioning system (GPS), data logger, pressure and temperature sensor, airspeed sensor, triple-axis gyro, and accelerometer. By combining the APM with an open-source mission planner software (APM Planner), most remote control model airplanes could be converted to an autonomous drone.

We based our prototype drone on a popular model airplane (Hobbyking Bixler; hobbyking.com). This airplane is relatively inexpensive (<$100), lightweight (~650g), and has ample room within its fuselage for installing the APM and an onboard camera. During our field tests, the drone was powered by a 2200 mAh (milliampere-hour) battery, which allowed it to fly for ~25 minutes per mission, and over a total distance of ~15 km.

Fig. 1. The prototype of the Conservation Drone used in test missions in Sumatra, Indonesia.

Fig. 2. APM Planner software used to plan the flight paths of each drone mission.

We equipped the drone with one of two still-photograph cameras during its test flights. The first was a Canon IXUS 220 HS (resolution: 4000 x 3000 pixels; sensor: Complementary Metal-Oxide-Semiconductor; sensor size: 6.17 x 4.55 mm). The second was a Pentax Optio WG-1 GPS (resolution: 4288 x 3216 pixels; sensor: Charge-Coupled Device; sensor size: 6.17 x 4.55 mm). Either camera was placed within the airplane's fuselage at about 15 cm behind the nose. To allow for extension of camera lens, a rectangular window was excised from the floor of the fuselage (~3 x 4 cm).

We replaced the original firmware of the Canon camera with a Canon Hack Development Kit (chdk.wikia.com). This 'hacked' firmware allows us to implement a customized intervalometer script to command the camera to take photographs at user-specified time intervals (e.g., every 3 seconds). This script also allows the user to define several other parameters including: i) time-delay before the camera begins taking pictures, ii) focal length of camera lens, and iii) time before camera automatically shuts down and retracts its lens. We used the Pentax camera without modification as it already has a built-in interval shot function.

The Conservation Drone can also be equipped with a video camera. We used a GoPro HD Hero camera housed within a protective shockproof casing (gopro.com). This camera was attached to the belly of the plane and pointed at ~45 degrees forwards and downwards. During our test flights, all video footages were taken at a resolution of 1080 x 720 pixels and at 60 frames per second.

Using the APM Planner (version 1.1.26), we programmed the flight path of each mission by clicking on waypoints in a Google satellite map interface (Fig. 2). The drone can be programmed to take off and land autonomously, and circle over any waypoint for a specified number of turns or duration. Users could also program other flight parameters such as ground speed and altitude of each waypoint. Each pre-programmed mission was uploaded to the drone, which would then fly the mission autonomously.

Study area

The prototype Conservation Drone was test-flown in a study area ('area 242'), located adjacent to the Gunung Leuser National Park in Sumatra, Indonesia (Fig. 3). The vegetation of our study site largely comprises regrowth lowland rainforest that had been selectively logged in the 1970s [10]. Both our study site and the national park are part of a broader Leuser Ecosystem that contains the last few contiguous lowland rainforests in Sumatra. This ecosystem is known to contain important habitats for Sumatran orangutans (*Pongo abelii*), elephants (*Elephas maximus sumatranus*) and tigers (*Panthera tigris sumatrae*) [11].

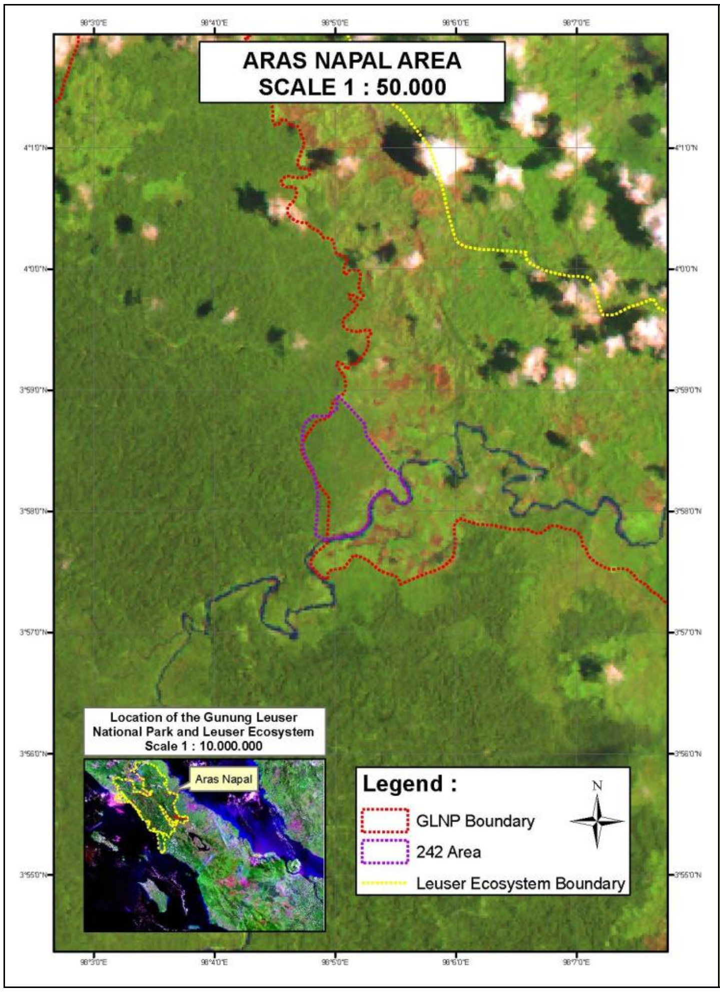

Fig. 3. Map of study area where test missions were conducted.

Missions

We conducted our test flights between 13 and 16 February, during which we flew 32 successful missions with the drone. The main aim of these missions was to obtain photographs and videos on land use and human activities within our study site. Here, we describe three of these missions (Fig. 4).

The first was a simple transect mission, in which the drone was programmed to fly at an altitude of 100 m above ground for a total distance of ~4 km, over an area that is known to be heavily degraded (Fig. 4a). The purpose of this mission was to demonstrate the use of the Conservation Drone for monitoring human activities in and around forests.

We designed the second mission to be a grid of flight paths that covered ~50 ha (~10 km total flight distance) of a predominantly forested landscape (Fig. 4b). For this mission, the drone was programmed to fly at 180 m above ground, at a speed of 10 m s^{-1}, and to take photographs every 10 seconds. These flight characteristics ensured sufficient overlap (>50%) between photographs to allow for the creation of a geo-referenced mosaic for subsequent spatial analysis (e.g., quantifying areas of different land uses).

The third was a river mission that followed a section of the Besitang river (Fig. 4c). The drone flew at 100 m above ground for a total distance of ~6 km. This mission demonstrates the use of the drone for surveying river ecosystems.

The first and second missions were flown twice: once with the Canon or Pentax camera, and then with the GoPro video camera. Photographs taken by the Canon and Pentax camera were subsequently geo-tagged, using a freeware (Geosetter; geosetter.de), with information on geographical coordinates of flight paths that were logged by the APM.

All photographs shown in the following sections were either taken by the authors or adapted from GoogleEarth or from LandSat.

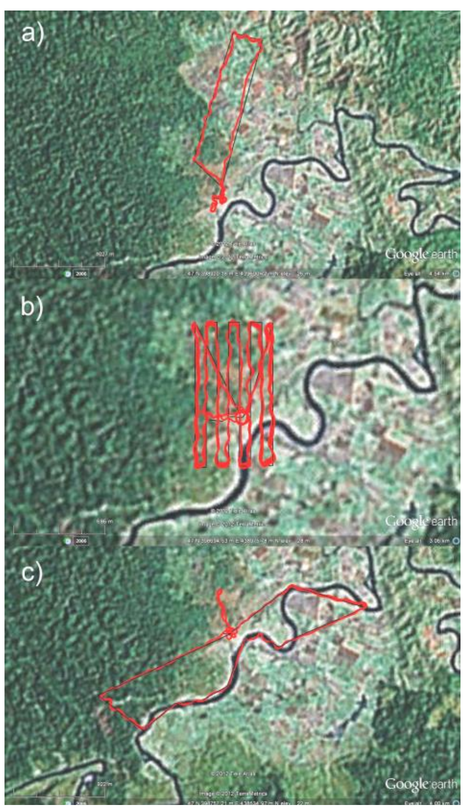

Fig. 4. Three test missions flown by the Conservation Drone. a) simple transect mission; b) grid mission; and c) river mission.

Results

Land use/ cover mapping

In the images acquired during our transect mission, we could easily distinguish different land uses, including oil palm plantations (Fig. 5a), maize fields (Fig. 5b), human habitation (Fig. 5c), forests (Fig. 5d), logged areas (Fig. 5e), and forest trails (Fig. 5f). These geo-tagged photographs and the flight paths of each mission could also be superimposed on Google Earth (Fig. 6), which allows for easy visualization of the location of features of interest from the photographs.

Using commercially available software (e.g., Autopano giga; kolor.com/), we produced geo-referenced mosaics from these aerial photographs (e.g., Fig. 7). These mosaics are essentially near real-time land use/ cover maps, which could be useful for local conservation workers seeking to monitor land-use change and illegal forest activities. An example is the mosaic produced from our grid mission, which is overlaid on a Landsat-based land use/ cover map (Fig. 7). The pixel resolution of our mosaic (5.1 cm) is 600 times higher than that of the Landsat-based map (30 m).

Human activity detection

Video footages acquired by Conservation Drones can complement still images and mosaics, particularly for detecting ongoing human activities. In video footages recorded at relatively low altitudes (80-100 m above ground), one could easily detect objects below the drone's flight path, including individual forest trees, oil palms, orangutans and elephants. When the drone was flying at 200 m above ground, activities in the larger landscape could also be monitored, including fires and recent logging. For example, in the video from the transect mission (youtu.be/IOm9v0Ewcek), one could clearly observe plumes of smoke rising from several locations in the landscape. This information could facilitate more targeted deployment of local rangers to patrol the problem areas.

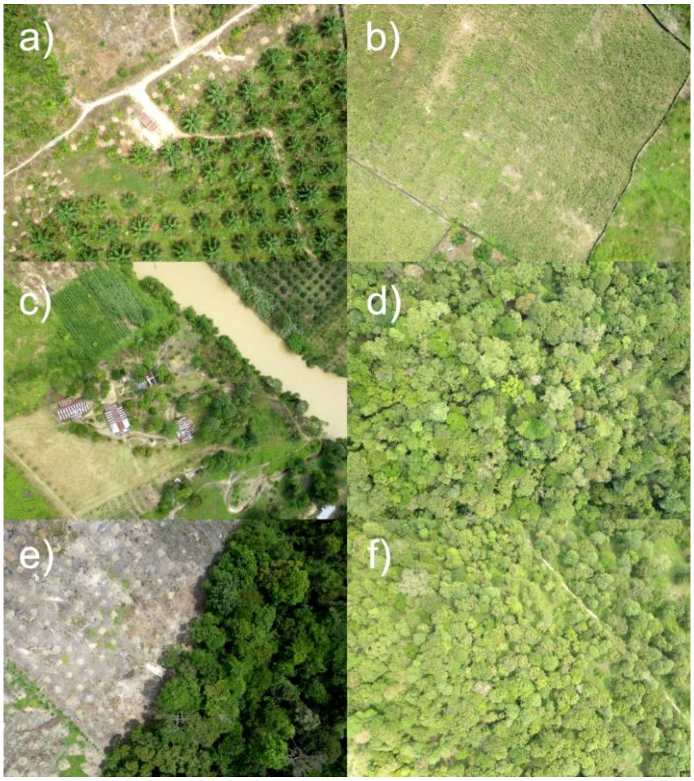

Fig. 5. Aerial photographs of land uses captured by the Conservation Drone. a) young oil palm plantation; b) maize field; c) human habitation: camp of the Elephant Patrol Unit in Aras Napal, Sumatra, Indonesia; d) forest; e) recently logged forest; and f) forest trail.

Biodiversity surveys

When equipped with a still-photograph camera, the Conservation Drone could document large mammals. A wild Sumatran orangutan was photographed while it was on top of a palm tree feeding on palm heart (Fig. 8a). A tame elephant was also clearly photographed, which illustrates how large wildlife species could be surveyed with this technology (Fig. 8b). Currently, studies of wild elephant populations often involve radio-collaring [12]. Based on the GPS telemetry data sent from these collars via satellite link to a researcher, a Conservation Drone could be deployed to the current location of the animal to acquire photographic and video information about its behavior, habitat and food resource utilization. Although no specific attempts were made to identify flora during our test flights, the resolution of the photographs is evidently sufficient to allow for identification of tree species based on canopy, fruit and flower characteristics [13].

Fig. 6. Geo-referenced mosaic and flight path of grid mission overlaid on Landsat-based land use/ cover map.

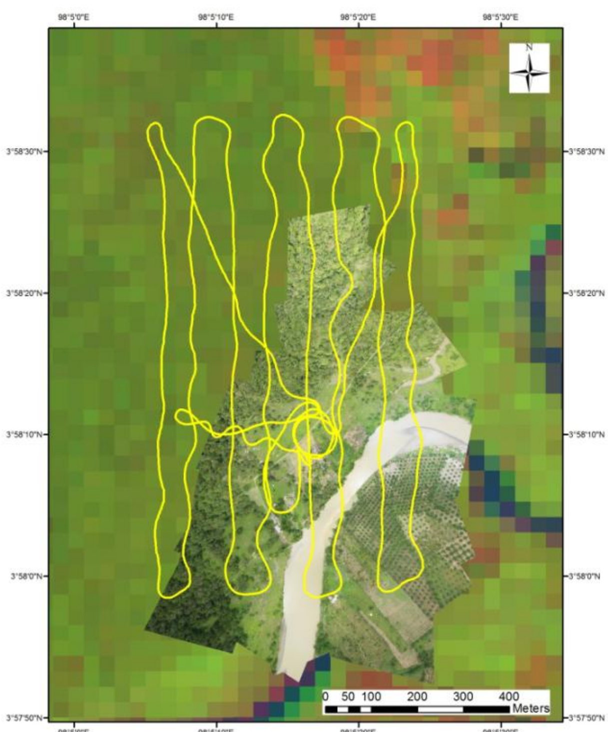

Fig. 7.Placement of geo-tagged photographs on Google Earth.

Discussion

Drone operation

A key consideration in developing Conservation Drones is their ease of use for non-specialist operators, who would mainly include conservation workers and field ecologists. Our prototype system already meets this criterion in most operating aspects, especially in the planning of each mission using the APM Planner. Equally noteworthy is the ability of the drone to take off autonomously with a light toss by the operator. Landing of the drone in a constrained space (<100 x 100 m) does require some manual control to avoid trees and other obstacles, as the drone circles down to the ground.

Over the 32 missions flown during our field tests, we found the drone to be 100% reliable in terms of flying its mission and returning to its launch site. We did not experience any crash. When flying against strong headwinds (>20 km h^{-1}), the drone did have a tendency to meander its way between waypoints, instead of flying a straight path. Therefore, to ensure best outcomes, we recommend the drone be operated only when wind speed is less than 10 km h^{-1}.

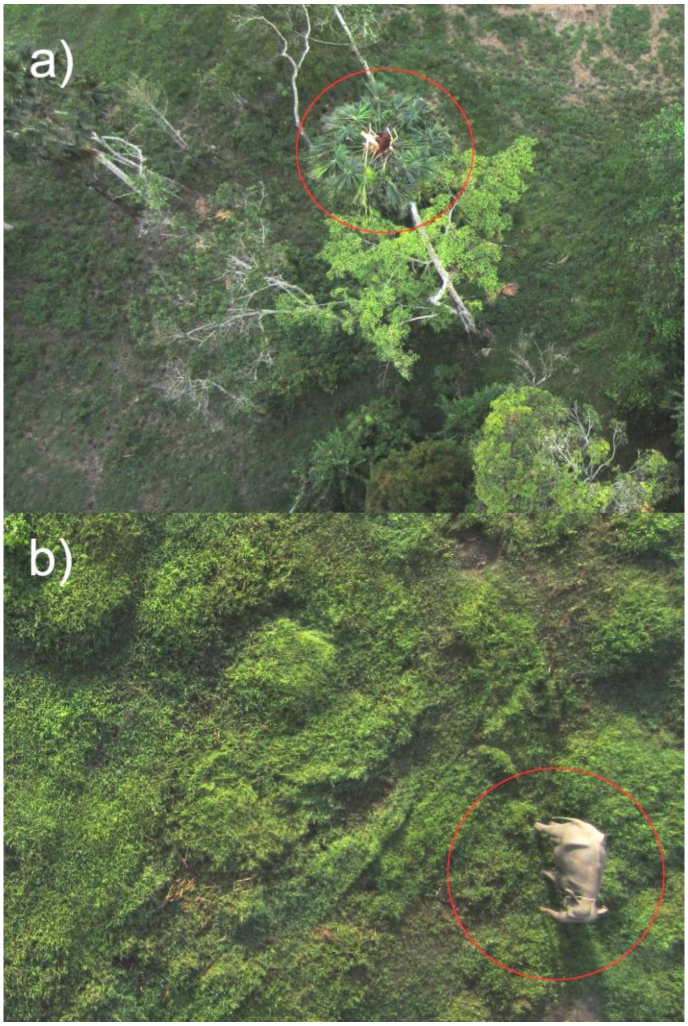

Fig. 8. Wildlife photographs captured by onboard camera. a) Sumatran orangutan; and b) Sumatran elephant.

Photo and video quality

Several factors determine the resolution of aerial photographs taken by the drone, including flight altitude, and the focal length and sensor size of the camera. The APM Planner includes a built-in application that allows the user to calculate picture resolution based on camera and flight settings. To illustrate a typical mission scenario, when flying 200 m above ground and at a camera focal length of 5.7 cm, we could capture images with a resolution of 5.3 cm per pixel, using either the Canon or Pentax camera (which have the same sensor size) (Table 1).

Table 1. Examples of achievable picture resolution under different combinations of camera and flight parameters.

Focal Length (cm)	Flight altitude (m, above ground)	Picture resolution (cm)
4.1	200	7.4
4.1	100	3.7
5.7	200	5.3
5.7	100	2.7
6.9	200	4.4
6.9	100	2.2

To compensate for movement of the drone in flight, we recommend setting the camera for automatic metering and focusing. Under this setting, our test photographs were taken at shutter speeds of between f1/320 and f/1000, which effectively avoided motion blur. During flight, the electric motor of the drone does produce vibrations which could result in vibration blur in photographs. As a solution, we created a vibration dampening system using low density packing foam (Fig. 9). We later discovered that the common kitchen sponge works equally well as a construction material. This instrument for Stable Placement of ONboard Gear and Equipment (iSPONGE) successfully removes vibration blur.

Land use change and human activity detection

The photographs and videos obtained during our test missions demonstrate the utility of the Conservation Drone for mapping and monitoring land use change. Larger crops, such as oil palm trees, could easily be distinguished (Fig. 5a); even relatively small crops, such as maize stands (Fig. 5b), could be identified from the photographs. The Conservation Drone can also acquire evidence of human activities in the landscape, such as logging (Fig. 5e), forest trails (Fig. 5f), and forest fires (youtu.be/IOm9v0Ewcek). Therefore, the drone could also facilitate enforcement of protected areas, particularly where constraints in conservation resources have led to forest encroaching and illegal forest activities [14]. Furthermore, owing to the negligible cost of operating the drone, target areas could be repeatedly surveyed at high frequency to monitor potential land use changes and activities.

However, we do recognize that a common problem of mosaic creation is the difficulty of stitching together photographs solely of forests. For example, the mosaic for our grid mission excludes substantial portions of forest in the northwestern part of the grid (Fig. 7). This problem arises because when flying at relatively low altitudes, the same emergent tree captured from different perspectives in different images was interpreted to be different trees by the stitching software. This results in the failure of the software to detect common features in a series of photographs, which is crucial for mosaic creation. The solution is to fly the drone at higher altitudes (e.g., 300 m above ground) to minimize such perspective discrepancies; the camera focal length could be increased to maintain picture resolution.

Another potential application of the drone is for ground truthing. Conventional methods of classifying land use/ cover from satellite data requires ground truthing to assess the accuracy and reliability of classification outcomes. Given that the deployment of local workers for ground truthing is often costly in terms of time and financial resources (and practically impossible in the most remote and inaccessible areas), ground truthing is often only carried out for a very limited extent of the area being classified. In principle, Conservation Drones could be used for 'drone truthing' of satellite-based land use classification, since drones could be deployed more quickly and over larger distances than local researchers on the ground.

Fig. 9. The instrument for Stable Placement of ONboard Gear and Equipment (iSPONGE), which is installed in the Conservation Drone to avoid vibration blur in photographs.

Biodiversity surveys in other ecosystems

Both the photographic and video data obtained during our test missions were of sufficient quality to identify large animals such as orangutans (and their nests in tree canopies) and elephants. In principle, Conservation Drones could also be used in other ecosystems, particularly open habitat types such as woodlands or savannas. In those systems, Conservation Drones could obtain valuable information on wildlife abundance, distribution, as well as habitat and resource utilization. Drones could also potentially be used for surveying marine animals, such as turtles (based on their tracks on beaches), as well as dugongs in shallow waters.

Comparison with other drone systems

We are developing Conservation Drones as a low-cost alternative to commercially available unmanned aerial vehicles that have been used by the military, agriculture sector, and the film industry. Some ecologists have also started using commercial systems for surveying wildlife [15-18]. However, commercial drones can cost tens of thousands of dollars . For example, a commercially-produced prototype system for wildlife research in Florida cost $35,000 [17]. The quality of data acquired by Conservation Drones is comparable to some of these commercial systems (e.g., sensefly.com). Furthermore, commercial systems often have an integrated photographic camera, but not a video camera. Therefore, not only are Conservation Drones orders of magnitude less expensive, but they also allow for much greater flexibility in terms of the sensor system they can carry.

Another key advantage of Conservation Drones over commercial systems stems from the fact that Conservation Drones are based on hardware and software that are being developed by an open-source community. Therefore, as users demand and contribute new features and functionalities, this technology will continue to improve. This communal and crowdsourcing approach is highly efficient and cost effective compared to product development by any single research team. At the same time, the cost of producing Conservation Drones likely will decrease with the cost of its components, such as lithium-polymer batteries.

Fig. 10. Conservation Drone 2.0 that is under development and testing.

Future development and conclusion

We are currently building upon the success of our prototype system to develop Conservation Drone 2.0 (Fig. 10). Two key improvements we seek are a bigger payload and longer range. Conservation Drone 2.0 is based on another popular remote control model airplane (FPV Raptor), which has a 2 m wingspan, 50% larger than our prototype drone. Initial tests suggest that the new drone can carry a 5000 mAh battery, which could potentially increase its flight time and range to ~50 minutes and ~25 km, respectively.

We are also experimenting with the use of near infra-red, infra-red and ultra-violet cameras on Conservation Drone 2.0. These sensors could potentially facilitate automated land use/ cover classification from aerial photographs, as well as identification of warm-bodied wildlife and humans when flying at dusk or dawn.

The use of Conservation Drones could lead to significant savings in terms of time, manpower and financial resources for local conservation workers and researchers, which would increase the efficiency of monitoring and surveying forests and wildlife in the developing tropics. We believe that Conservation Drones could be a game-changer and might soon become a standard technique in conservation efforts and research in the tropics and elsewhere.

Acknowledgements

We thank the Leuser International Foundation for granting us permission to work in the area and using their facilities at the study site. In particular we thank A. Burhan, C. Cheng and S. Talaparu for their logistical support and technical assistance. This project is partly supported by the National Geographic Society, the Orangutan Conservancy, the Denver Zoo, the Philadelphia Zoo and the Swiss National Science Foundation.

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