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Drone-Based Land Cover Mapping in the African Rainforest: A Technical Report

Daiji Kimura

The Center for African Area Studies, Kyoto University
E-mail: daiji.kimura@gmail.com

Abstract The use of drones is expanding rapidly in field research, although their use in tropical African rainforests has not been widely reported. This seems to be because of two issues: the difficulty of flying drones in a tropical forest, and the difficulties that are peculiar to fieldwork in Africa. Based on my experience of operating drones in two regions, Cameroon and DR Congo, this paper provides a general explanation of the issues involved in shooting with a drone, and describes how these operational difficulties can be overcome during field research in a tropical forest setting.

Keywords: African rainforest; Cameroon; DR Congo; Drone; UAV.

Using a Drone in the African Rainforest

Drones or unmanned aerial vehicles (UAVs) have become a popular tool in various research fields, including plant and animal ecology (Wu et al. 2021; Zhang et al. 2016; Mulero-Pázmány et al. 2014), environmental research (Puliti et al. 2015), nature conservation (López & Mulero-Pázmány 2019), and anthropology (Mizuochi et al. 2019). Historically, the ground surface has been measured by direct observation or aerial photography. The Landsat satellite enabled image analysis from space that constituted a revolution in geographical research. However, Landsat images are coarse (30 × 30 m pixel size), and fine images of newer satellites such as Quickbird are expensive. It is also difficult to obtain images at the exact position and time that a researcher wants. Using a drone, researchers can obtain images at any location and time, although the range is narrower than those of satellite images.

Forest surveys by drone are conducted frequently in temperate and boreal zones (Wu et al. 2021; Puliti et al. 2015). There are some reports of drone use in tropical forests in Central and South America (Zhang et al. 2016; Sothe et al. 2019; Reder et al. 2019) and Southeast Asia (Paneque-Gálvez et al. 2014); however, only a few drone surveys have been conducted in tropical African forests (Thomson et al. 2018). This seems to be because of two issues: the difficulty of flying drones in a tropical forest and the difficulties that are peculiar to fieldwork in

Africa, such as political issues and delicate relationships with local residents.

Recently I conducted a land cover mapping exercise by drone in the rainforests of Cameroon and DR Congo. In both locations, Japanese research projects have been ongoing for a long time. Drone data obtained from these sites will be utilized in these projects. In this paper, I will explain how the difficulties of using a drone in African rainforests can be overcome, based on actual field experiences.

PREPARATION OF A SURVEY

Before describing the actual drone flight, I will explain the preparation required prior to using a drone in fieldwork. Drone technology is advancing so rapidly that the following description may soon become obsolete; however, it is meaningful for the use of drones under current conditions.

I. The drone body and other equipment

Drones can be roughly divided into two categories: airplane and multicopter types. The multicoptor type is most suitable for use in dense tropical forests because it can take-off and land vertically.(1) I selected DJI's 'Mavic 2 Pro'(2) (hereafter 'Mavic'), because of its portability (907 g weight and foldable), fine camera resolution (20 million pixels), length of flight time (up to 30 min), and ease of manual and autopilot control. The main body of the Mavic and "Fly more kit" costs about 2,000 USD.

Mavic can fly for about 30 min with a single fully charged battery, and it takes about 90 min to charge one battery. Therefore, if the researcher wants to fly a drone many times a day, some spare batteries are indispensable. If the remote research base does not have sufficient charging capacity, such as a large-scale solar battery system or generator, it will be difficult to operate the drone.

II. Remote control equipment

Because the controller for the Mavic has no screen, a smartphone connected with a USB cable (both Android and iPhone are available) needs to be used as a display. For manual control, the 'DJI Go 4' application should be installed on the smartphone. To shoot over a wide area, autopilot flight is necessary, and the 'GS Pro (Ground Station Pro)' application should be used.(3) Note that GS Pro works only on the iPad.

III. Tools for image processing

Many photographs are taken during autopilot flights, and they should be synthesized for further analysis. The digital image processing software 'Metashape'(4) is used for this work as a standard. Metashape (professional edition) costs 549 USD for an educational license. Using this software, not only flat maps (orthomosaic) but also 3D maps and a digital elevation model (DEM) can be combined.

Synthesizing many photographs requires more computer power. The computer should therefore have: (1) a large amount of RAM (preferably 64 GB or more), (2) a powerful graphics processing unit (GPU), and (3) fast storage (SSD is preferable). A desktop computer is better than a laptop for such specifications. Analysis is possible using a small laptop, but the software often stops operating when many images are being analyzed simultaneously.

IV. Preparation before entering the field

It is important to practise flying the drone and analyzing data before starting field work. Note that drone flight is restricted in some regions, such as urban areas or near airports. After taking some photographs during practice flights, all of the steps in the image synthesis should be tested. All equipment used during the practice flight should be listed for transport to the field. Even if a single USB cable is missing, drone shooting in the field cannot be completed.

If a drone has not been used for a certain period, its firmware may be old. Firmware updates should be completed beforehand. In the field, where internet connectivity is poor, downloading firmware data may be difficult. A satellite map of the research area should also be cashed with DJI Go4 and GS Pro in advance.

Flights in Cameroon

I. Study site

In Cameroon, I conducted a drone survey as a member of the Coméca[(5)] project in February 2019. The aim of the project was to establish the sustainable use of wildlife and non-timber forest products (NTFPs) in the tropical rainforest of southeast Cameroon, with a focus on the following:

- Hunting and agricultural activities of local people.
- Ecological potential of NTFPs.
- Estimation of the density of wild animals.

For these surveys, a wide and precise land cover map is indispensable and, therefore, a drone survey was conducted.

The research station of the Coméca project was established in Gribé village in the Eastern Province of Cameroon (Figure 1). This village is located near Boumba-Bek National Park. Slash-and-burn crop fields and secondary forest are located around the village, which are in turn surrounded by a vast expanse of primary forest.

II. Flight authorization

Before operating a drone in Cameroon, it is necessary to obtain flight authorization. In some countries in Africa (e.g., DR Congo, as explained later),

Figure 1 Map of the research areas.

the regulation of drones is not yet clearly established, but in Cameroon application forms are available from the Cameroon Civil Aviation Authority. The information required is as follows.

1. **The exact period over which flights will be performed.**
2. **The geographic coordinates of the area to be overflown.** It is prohibited to fly a drone near a military airfield or national border. In my case, there were no problems regarding the area to be surveyed.
3. **The description of the contingency measures in the event of a failure of the remotely piloted aircraft, loss of the command and control link, or loss of visual contact with the aircraft.** In the application, I wrote: "The drone flies at a height of 100 m or more according to the autopilot, and therefore it is unlikely to become uncontrollable. In case of an emergency, it is possible to return the drone to its departure point using the automatic return function."
4. **The identity of the pilot (name, date and place of birth, nationality).**
5. **Documents attesting to the technical aptitude of the remote pilot and their ability to handle the model of remotely piloted aircraft used in the context of the planned operation.** I obtained a document of certification from the director of my institution, containing the following text: "He has had experience in handling drones since 2016 in Japan, and has the ability to take photographs while flying drones securely."
6. **Documents relating to an analysis of the risks linked to the operation.** For drone operation, I showed a URL link to the DJI manual. Regarding

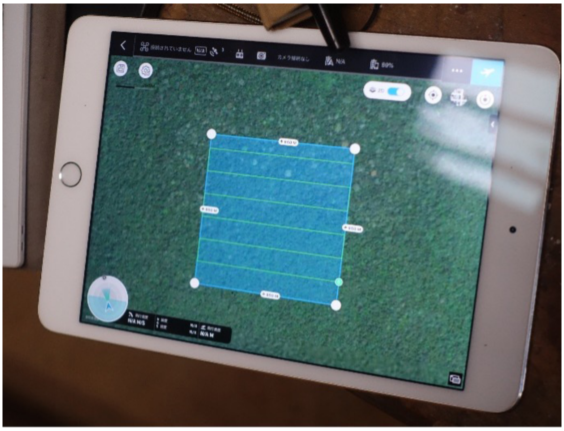

Figure 2 Control screen of the GS Pro.

the danger of operation, the same explanation as in item 3 was given.

7. **An insurance policy covering the period of the planned transaction.** I obtained drone insurance in Japan, and submitted the English documents, translated by myself.

By submitting this documentation with a covering letter from the project manager of the local counterpart institution IRAD,(6) authorization was obtained in about two weeks.

III. Flight planning

During the survey in Cameroon, I aimed to take photographic images covering all fields and secondary forest around Gribé village.

Using the autopilot application (‘GS Pro’ in this case), the drone was able to automatically fly in a zigzag pattern and take photographs over the designated areas. The drone was guided by GPS positioning during the flight. The flight area can be confirmed(7) by watching the satellite image (Figure 2).

When a drone flies at a high altitude, the range of a one-shot image becomes wider and, therefore, the range covered by one flight mission also becomes wider. However, the resolution of the image is reduced at higher altitudes. The range width and resolution are therefore in a trade-off relationship. After some trial flights, I decided to shoot a 600 × 600 m square in one flight mission at an altitude of 200 m. Tree leaves were observable at this height (Figure 3). This autopilot flight took 15 to 20 min, while the Mavic’s cruising time was 30 min.

With this flight plan it took three days to complete the shooting of the Gribé area (Figure 4). To combine 600 × 600 m images and draw a larger land cover map, these images had to be overlapped at each edge. To produce such overlaps correctly I made a copy of the previous mission and transformed it when creating a new mission on the GS Pro control screen.

Figure 3 A canopy image taken from a height of 200 m.

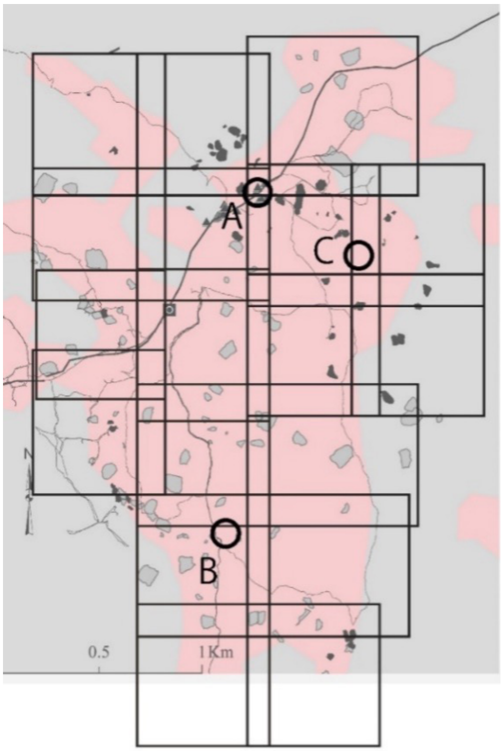

Figure 4 Flight plan at Gribé. Each square shows the area covered during one flight mission. Circles show the take-off points. A: Research base, B: Crop field, C: A small settlement of the Baka.

IV. Flying the drone

Here I will explain the actual flight, focusing on the following difficulties that are peculiar to tropical rainforest.

1. Take-off, landing, and low-altitude flying are difficult in a dense forest.
2. If the drone flies far away, it disappears from view. Radio waves can then become obstructed.
3. If a drone falls into the forest, it can be difficult to locate and recover.

For a multicopter drone, take-off and landing are easy in open locations. I therefore launched the drone from open places, such as the village(8) or large crop fields, when possible. However, when filming far from such open areas, I had to find a location where the canopy directly above the take-off point was clear (Figure 5). Even in such places, problems frequently occurred. Sometimes, the drone's collision prevention sensor detected tree branches and stopped flying upwards. In another case, the drone became uncontrollable, hit a branch, and fell to the ground. At the time of the autopilot flight, the take-off point and landing point were planned to be the same, but actually they deviated slightly. In this case, I had to land the drone by manual control. Conditions on the ground during take-off/landing are also important. In the forest, it was difficult to locate a flat place with no weeds or tree branches. I therefore used a 1 × 1 m piece of cardboard as a 'heliport' (Figure 6).

At Gribé, I also flew a drone manually to observe the flowering of the *Irvingia gabonensis* tree.(9) I had to fly the drone manually at a low altitude. The drone had a collision prevention sensor, but there was still a risk that the drone would hit a tree and fall. The researcher should be well trained beforehand in manual maneuvering.

In the forest, the aircraft immediately disappeared behind the canopy. Although its position was displayed on the controller, it was difficult to control the drone without being able to view it. Additionally, the wireless connection was interrupted at a distance of around 2 km. In such cases, autopilot flight was possible, but I returned the drone because the flying conditions were not confirmed. The aircraft had to take-off in the forest when filming in locations far from the village (Figure 4). For checking my own position in the forest, GPS applications for smartphone (e.g., 'Geo Tracker' for Android, or 'Gegraphica' for iPhone) were useful because the map of the satellite image was displayed more clearly than in ordinary GPS devices, such as a Garmin instrument.

During the survey of Gribé, I experienced a drone crash. When I first tried flying it with autopilot, I made a mistake in setting the return method. I mistakenly set the method to 'automatic landing', not realizing that the drone would descend at the very point where the filming ended. It should have been set to "automatic return", which would return the drone to the starting point, where it would then land. Thus, the drone descended into the forest about 200 m from the research station and disappeared. It was still possible to communicate with the drone by wireless connection, so I switched to the manual control application (DJI Go 4) and obtained the scene that the drone was catching. GPS position data were also

Figure 5 Drone flight in the forest. A flying drone is indicated by a white oval. (Photograph by N. Matsuura).

Figure 6 ‘Heliport’ and other equipment used in the forest flight.

acquired. Using these two data sources as a guide, my research assistant and I searched the expected area. After 4 h, we found the drone body stuck on a tree branch. A propeller was slightly damaged, but the main body was safe. Therefore, if the drone is still active following a crash, the GPS position and image that the drone is catching should be recorded immediately.

V. Relationships with authorities and local people

During the survey of Gribé, there were good relationships with local authorities and villagers because I obtained an authorization from the Civil Aviation Authority of Cameroon. I submitted a copy of the authorization document to the prefectural office in Yokadouma and to the commanding officer of the gendarmerie in Ngatto-Nouveau village. I did not give a detailed explanation to the villagers in Gribé, but they observed drone flight with no particular interest.

Flights in DR Congo

I. Study site

I also conducted a drone flight in DR Congo from August to September 2019. The research area was around Wamba village in Tshuapa Province (Figure 1). This village is located in the Luo Scientific Reserve. Using this village as a base, primatological research on bonobo (*Pan paniscus*) has been conducted since 1973 (Furuichi et al. 2011). I had previously conducted anthropological studies in this area with other researchers (Kimura ed. 2015).

II. Flight authorization

To acquire the flight authorization in DR Congo, I prepared documents similar to those in Cameroon and submitted them to the Aviation Civile in Kinshasa about four months before the start of the survey. The application was accepted, but I could not obtain the authorization after all. According to the person who assessed the application, DR Congo did not yet have a law regulating drone flights. I consulted the staff of our counterpart institution CREF,[(10)] and was advised that I should discuss the situation in detail with local authorities and villagers. I was also told me that when I next request permission to conduct research in Wamba, a drone should be listed as essential survey equipment.

III. Flight planning

At Wamba, I aimed to shoot the entire area where bonobo research was being conducted. However, there was not enough time to complete this task and, therefore, only the area centered on the research station was filmed. The altitude of the flight was set to 250 m, and one flight area was 900 × 900 m^2 (Figure 7). It took 11 days to complete the shooting.

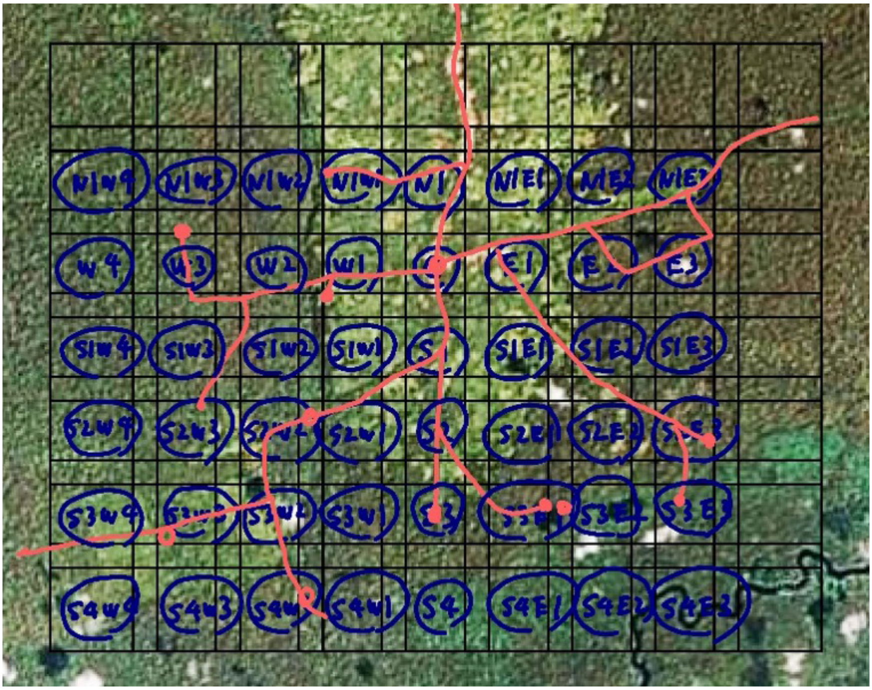

Figure 7 Flight plan of Wamba. Each square (900 × 900 m^2) shows the area covered during one flight mission.

IV. Flying the drone

Because the target area was wider than that used in Cameroon, I flew the drone from the forest area more often. In some cases, I found a small forest camp for take-off; in other cases, I flew it from open forest areas along the riverside. My assistant cut away the dense vegetation from around the take-off point, and the cardboard 'heliport' was used. The weather was also important. Of course, drone should not be flown in the rain. One day, I attempted to fly the drone at around 8:00 a.m., but the flight was not successful because of a layer of thin fog covering the area. Such conditions can occur in the morning in tropical rainforests.

I experienced another drone crash in Wamba. In one flight, the drone motor stopped some minutes after take-off, and it crashed into the forest from a height of about 250 m. I tried to confirm its position with the GPS, but communication was lost. Fortunately, my assistant visually recognized the approximate position of the crash. After a 1 h search in the forest, we were able to locate the aircraft. Because the battery was missing from the recovered drone, it is highly likely that the battery had not been properly inserted into drone body at the start of the flight, and it was displaced during the flight.(11) The recovered aircraft was safe, and I was able to continue the shooting.

V. Relationships with the authorities and local people

When entering DR Congo, drones may cause problems at customs. Also, while traveling in Congo, the Direction Générale de Migration (DGM) may confiscate drones. Formal authorization of drone use will be helpful in such cases.

Because I could not obtain authorization to use a drone in this research, I directly explained the aim and safety of drone flight to the Administrateur Territoire (AT) of the Territoire de Djolu and the chief of Wamba village. They approved my research without any issues. During the shooting work, the villagers watched the drone flight with interest, and no particular problems occurred until near the end of the research.

A few days before my departure, a rumor was identified by my research assistant that some villagers were saying, "Kimura (me) can see people naked with the drone." This was not possible because my drone was filming from an altitude of 250 m. Even if a human was photographed, it was only possible to confirm whether he or she was present, and the shape of the body could not be determined. I therefore asked the assistant to explain this to the villagers. However, a few days later, some villagers who were members of a human rights group claimed that I had photographed naked women washing at a stream. It was clear that this was a false accusation. I explained this by showing the actual drone pictures to the villagers, but they did not listen to me. Ultimately, I was required to pay a certain amount of money as an apology.

As can be seen from this example, a novel research instrument like a drone can create certain problems with the local people. In particular, the drone may cause people to worry if it flies over their own village (Smith 2015). The lesson learned at that time was that I should have fully explained the purpose of the drone to all villagers, and I should have worked more closely with local authorities in preparation for such problems. It would also be good practice to inform all villagers of the date and location of each flight in advance, and to then show them images taken during the flight.

Data Analysis

Thousands of aerial photos were obtained from the drone flight in the field. They must be synthesized for further research. From data such as the focal length of the drone camera, shooting angle, and GPS data, the software 'Metashape' can create ortho-mosaic images (Figure 8), 3D maps (Figure 9), and a DEM (Figure 10).(12)

In the field, I conducted the preliminary processing of one flight (about 100 images) with a laptop. However, when trying to synthesize the data from several flights at once, the work overloaded my laptop (Lenovo ThinkPad X1 Carbon), and Metashape stopped in the middle of the process. Therefore, large-scale processing had to be performed after returning to Japan.

I used Dell Alienware m17(13) with 32 GB memory and fast GPU for the processing in Japan. Even using this machine, it was not possible to synthesize all of the images taken in Gribé or Wamba in one attempt, and the following three-step process was required.

1. Synthesize the images obtained in one flight through a normal composition workflow.
2. Merge some of the composited rectangles (chunks) using the function of 'merge chunks'.(14) If there are too many chunks, the merging will not work. For compositing, it is necessary to specify some coincidence points in the overlapping area of the chunks.
3. Some merged chunks are processed again by "merge chunks" to synthesize the whole land cover image.

Figure 8 is a map synthesized following the procedure above. Because the number of images being processed at once depends on the power of the computer, the processing limit at each step should be determined by trial and error.

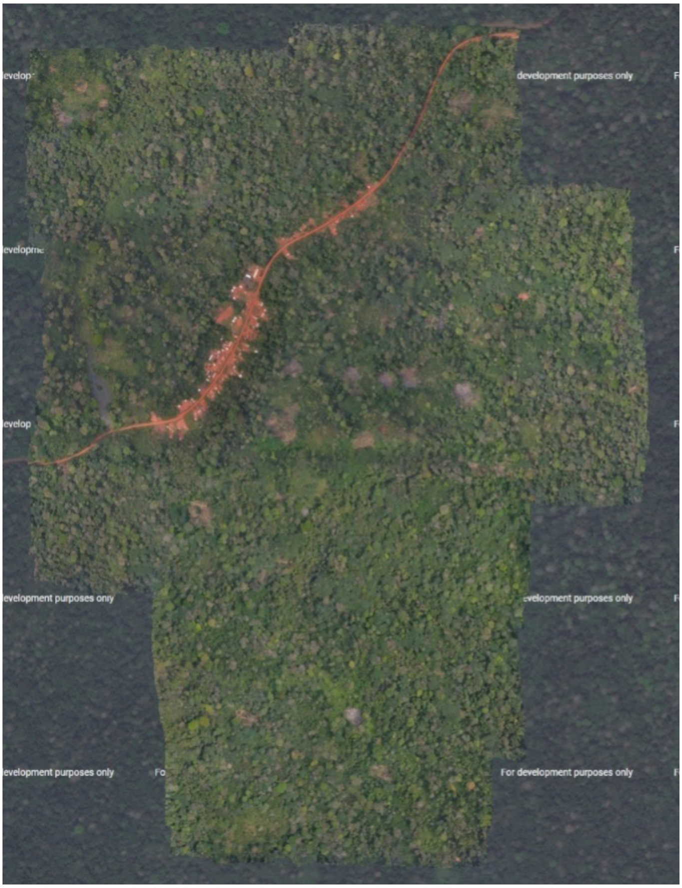

Figure 8 Synthesized photographs of Gribé forest.

Figure 9 A 3D model of Gribé village.

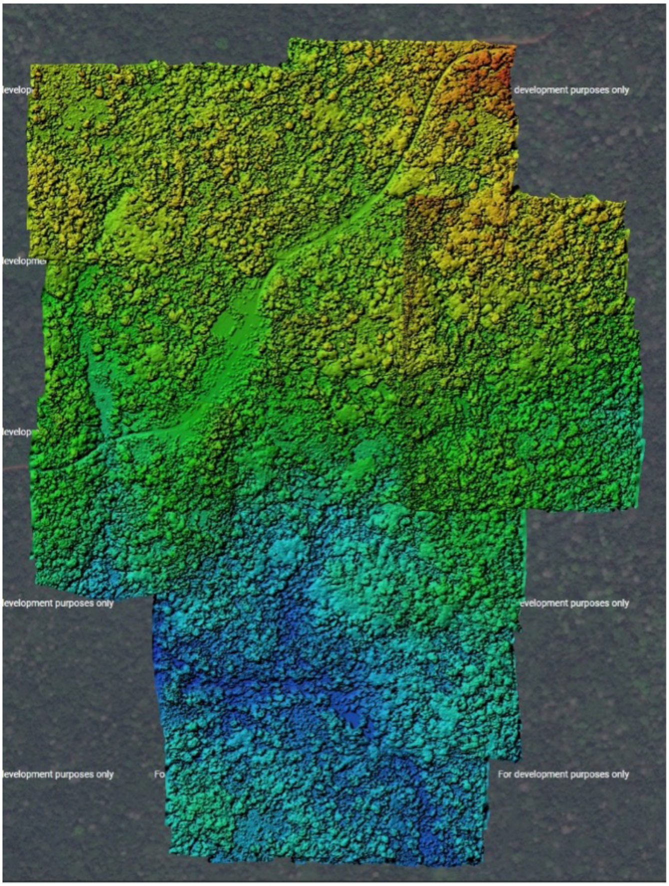

Figure 10 Digital Elevation Model of Gribé forest. The high land is a red color and the low land is a blue color.

AREAS OF RESEARCH IN WHICH A DRONE IS REQUIRED

Land cover images are easily available through internet services such as Google Maps. A drone is therefore not absolutely necessary for geographical studies. However, there are several research areas for which the use of a drone is advantageous. First, unlike satellite remote sensing, images can be acquired anytime, just by flying a drone. It is possible to analyze seasonal forest phenology or annual changes in shifting cultivation in detail. Second, high-precision images that show individual leaves and flowers on a tree can be obtained by a low-flying drone. Individual plants can be identified by such images.

The following are examples of surveys that can be conducted by drone in tropical African forests.

I. Drawing a land cover map

Using drones, land cover maps of a research area can be created that include villages, fields, secondary forest, primary forest, and rivers. Measuring crop fields is usually done by GPS, but by using drones it is possible to locate fields even in the deep forest. At Wamba, drones have discovered illegal logging activities that researchers were unaware of. At Gribé and Wamba, drone pictures have been combined with GPS data to promote the study of forest use by local people.

Drone images are also useful in ecological surveys. At Gribé, animal densities have been investigated by line census and camera traps. A long-term bonobo survey has been conducted at Wamba. Drone data obtained during this time will form the basis of further studies. Anthropological studies have also been conducted in these research sites. The land cover maps can be used in studies of deforestation status and the use of NTFPs.

II. Vegetation surveys

Because drones can take detailed pictures from low altitudes, they can be used in vegetation surveys. However, compared to boreal and temperate forests, which typically have few tree species, tropical rainforests consist of a large number of species. It is therefore difficult to identify each tree from drone images. Even local informants with a rich botanical knowledge cannot easily identify tree species from drone images. Many of them have no experience of looking at trees from above. However, some characteristic trees (e.g., oil palm (*Elaeis guineensis*) and umbrella trees (*Musanga cecropioides*)) can be identified easily. Because oil palms are mainly distributed by humans (Ferreira et al. 2020), the distribution data of this species can be used to analyze the transition of sedentary area. Because the umbrella tree is characteristic of young secondary forests after cultivation, it is possible to study the long-term change of land use by examining the distribution of this tree.

Useful plants, such as *Irvingia gabonensis*, can be photographed by a manually controlled drone. By investigating the stage of flowering, the annual fluctuation of the yield of this species can be studied. Also by shooting trees that are left uncut in crop fields, we can determine which species are used by local people.

III. Animal surveys

Another activity that can be conducted by drone surveys is animal research. In open areas, such surveys have been conducted on rhinoceros (Mulero-Pázmány et al. 2014) and elephants (Vermeulen et al. 2013). Chimpanzee nests have been censused in African woodland areas (Bonnin et al. 2018; van Andel et al. 2015) and orangutan nests have been counted in Borneo (Milne et al. 2021). In the rainforest, however, animals cannot be easily investigated by drone, because they usually stay hidden under the canopy. In some research sites, animal surveys are being conducted using infrared cameras (Kays et al. 2019). Recently, DJI has released a drone model with a pre-installed infrared camera.[(15)] Technological progress in the near future will enable us to conduct animal research by drone in rainforests.

Conclusion

Drones have become widely used in field research. In African rainforests, however, there are some specific difficulties regarding drone use. First, due to the dense forests, there is a risk of damage during take-off and landing, as well as during the flight. Researchers should be well trained in preparation for these risks. Second, due to the lack of relevant legal system, it may be difficult to obtain a flight permit in some African countries. When conducting field work without permission there may be trouble with the local authorities or residents. In this paper, I have described my experiences regarding these matters in Cameroon and DR Congo, providing guidance for the use of drones in future field research in Africa.

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Notes

(1) However, the airplane type has also been used in some past tropical forest surveys.

(2) As of 2022, a new model called 'Mavic 3' has been released, but it is not compatible with the autopilot software GS Pro described below. When purchasing a drone, it is necessary

to check for compatibility with autopilot applications. DJI's 'Phantom' series is another option, but it is too large and heavy to carry into the field.

(3) Both DJI Go 4 and GS Pro are produced by DJI, and both applications are available free of charge.

(4) Metashape is a product of Agisoft. It was formerly called 'Photoscan'. This software runs on Windows, Mac, and Linux.

(5) Coméca is an abbreviation of "Co-creation of Innovative Forest Resources Management Combining Ecological Methods and Indigenous Knowledge". This project is supported by the Japan International Cooperation Agency (JICA) and Japan Science and Technology Agency (JST).

(6) Institute of Agricultural Research for Development. Our counterpart organization in Cameroon.

(7) Usually a '3D Map Area' was used.

(8) When I tried to fly the drone near the wire fence of the Gribé research station, a 'magnetic interference error' occurred and the drone did not fly. In front of the parabolic antenna used for Internet connection, communication with the drone became unstable. It was necessary to pay attention to such conditions.

(9) The kernel oil of *Irvingia gabonensis* is an important product for the local people.

(10) Centre de Recherche en Écologie et Forestérie.

(11) After this accident, I confirmed the correct insertion of the battery prior to every flight.

(12) For detail, refer to the Metashape manual (https://www.agisoft.com/pdf/metashape-pro_1_8_en.pdf).

(13) Alienware m17 is a laptop. I was planning to use it in the field to conduct data processing. However, because it consumed a lot of electricity, it proved difficult to use in the field.

(14) If each chunk was shot at a different time of day, the direction of sunlight changes and the shadows are cast differently. This can result in a dappled composite image.

(15) https://www.dji.com/mavic-2-enterprise

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