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A practical approach with drones, smartphones, and tracking tags for potential real-time animal tracking

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Abstract

Drones are increasingly used for fauna monitoring and wildlife tracking; however, their application for wildlife tracking is restricted by developing such systems. Here we explore the potential of drones for wildlife tracking using an off-the-shelf system that is easy to use by non-specialists consisting of a multirotor drone, smartphones, and commercial tracking devices via Bluetooth and Ultra-Wide Band (UWB). We present the system configuration, explore the operational parameters that can affect detection capabilities, and test the effectiveness of the system for locating targets by simulating target animals in savanna and forest environments. The self-contained tracking system was built without hardware or software customization. In 40 tracking flights carried out in the Brazilian Cerrado, we obtained a detection rate of 90% in savanna and 40% in forest areas. Tests for targets in movement ($N = 20$), the detection rates were 90% in the savanna and 30% in the forest areas. The spatial accuracy obtained by the system was 14.61 m, being significantly more accurate in savanna ($\overline{x} = 10.53$) than in forest areas ($\overline{x} = 13.06$). This approach to wildlife tracking facilitates the use of drones by non-specialists at an affordable cost for conservation projects with limited resources. The reduced size of the tags, the long battery life, and the lower cost compared to GPS-tags open up a range of opportunities for animal tracking.

Key words: conservation drone, small, surveys, wildlife tracking.

During the last half century, wildlife tracking has made a major impact in ecology and conservation biology (Kays et al. 2015). Aimed at investigating animals' movement, wildlife tracking is one of the main tools to explore species' behavior and ecology in diverse habitats (Lahoz-Monfort and Magrath 2021). Over the years, new technologies have been used for wildlife tracking: conventional radio telemetry (very high frequency, VHF); Argos Doppler tags (aka platform transmitter terminals, PTTs) based on the satellite network ARGOS System (https://www.argos-system.org), and Global Navigation Satellite Systems (GNSS) tracking tags. Although GNSS-tracking provides the best spatial and temporal resolutions, the small size of many animals limits the use of this technology, as tags are often too large or heavy to be fitted to subject animals (Cooke et al. 2004). The smallest GNSS-tracking device with data download via Bluetooth technology weighs 15 g (Thomas et al. 2011), and considering that tracking devices should not weigh more than 3–5% of the animal body mass (Kenward 2001), the use of GNSS-tracking devices currently available are limited to animals heavier than 500 g. In addition, the high cost of these devices, which can reach approximately $1,500 with manual download or $4,000 with remote download services (Thomas et al. 2011), is another challenge to be overcome by researchers and which currently limits the use of this technology in ecology and conservation studies.

In recent years, the use of drones (Unmanned Aerial Systems, UAS) has gained popularity in wildlife studies (Schiffman 2014; Jiménez and Mulero-Pázmány 2019). Both on terrestrial and aquatic ecosystems, drones are increasingly used for fauna monitoring (Linchant et al. 2015; Lyons et al. 2019), to study species' spatial distribution (Mulero-Pázmány et al. 2015; Baxter and Hamilton, 2018), and for wildlife tracking (Cliff et al. 2018; Nguyen et al. 2019). The main benefits of UAV-based Radio Tracking Systems (also known as UAVRTS) when compared with conventional methods are the reduction of logistical and labor-intensive challenges in the field and the increase of fieldwork operational safety (Linchant et al. 2015; Cliff et al. 2018). In addition, UAVRTS studies have shown that these systems present a significantly stronger signal than ground-based ones, which helps in detecting species such as small forest birds (Tremblay et al. 2017), and may provide localization estimates with 53% less error than those obtained by experienced radiotelemetry users (Shafer et al. 2019).

Currently available UAVRTS use the principle of conventional radio telemetry for wildlife localization in 2 ways: 1) range-based or 2) bearing-based (Hui et al. 2021). Range-based, such as those developed by Santos et al. (2014) and Nguyen et al. (2019) are less difficult to build than bearing-based systems because the antenna configuration is simpler (Cliff et al. 2018; Dressel and Kochenderfer, 2018). However, for both systems, considerable technical knowledge is still needed both for the development and customization of the hardware and for data analysis, generally based on estimation approaches such as particle, grid, and Kalman filters (Dressel and Kochenderfer 2018; Nguyen et al. 2019). Thus, the application of drones for tracking wildlife is restricted to those users with the technical capacity to develop such systems.

Here, we explore a practical approach to potential wildlife tracking using an off-the-shelf system consisting of a multirotor drone, smartphones, and tracking tag which is easy to use by non-specialists. Specifically, we describe the setup of the system, explore operational parameters that can affect detection capability, and test the system's effectiveness in locating targets that simulate tagged animals in open and forest-covered environments. To our knowledge, this is the first experiment where drones are associated with off-the-shelf Bluetooth and Ultra-Wide Band (UWB) technologies for wildlife tracking.

Materials and Methods

Off-the-shelf tracking system overview

The off-the-shelf tracking system we developed is formed by a DJI Mavic Pro multirotor drone (https://www.dji.com/br/mavic), 2 smartphones (Iphone model 8 and Iphone model 11, Apple Inc.), and tracking tags known as AirTags from Apple.inc (Figure 1). To assemble the system, we created a structure to attach the iPhone 8 to the Mavic Pro drone (Figure 1B) using pre-existing models in 3D printing webpages (https://www.thingiverse.com/). AirTags (https://www.apple.com/airtag/) are Apple tracking tags (diameter = 31.9 mm; thickness = 8.00 mm; weight = 11 g), with IP67 water resistance (IEC 60529); with a built-in speaker; which features Bluetooth technology with a transmission capacity up to 100 m; an UWB support; an accelerometer sensor; and an estimated battery life of 1 year (Figure 1C). UWB is similar to Wi-Fi and Bluetooth technology but that has a significantly higher bandwidth than most narrowband signals used in communications, with low-power signals, less interference, and low energy consumption.

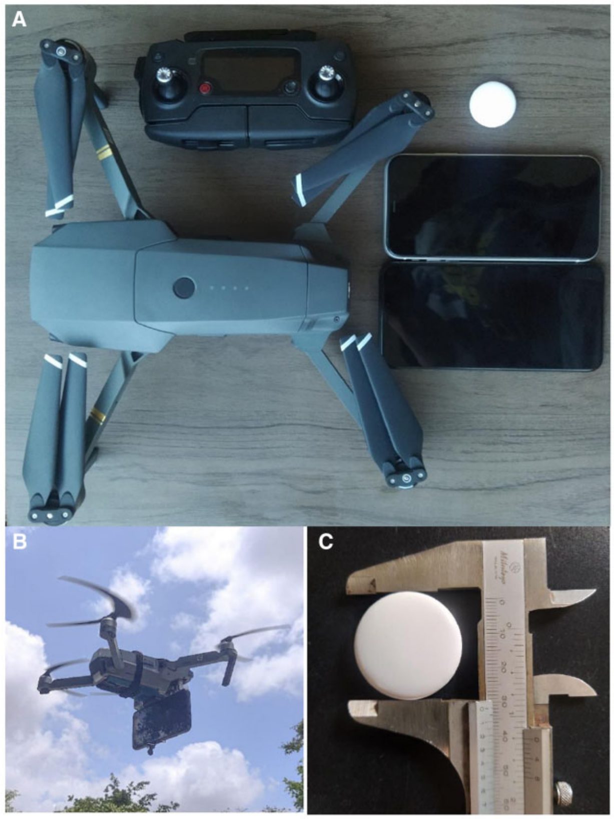

Figure 1. Off-the-shelf tracking system and components. (A) Off-the-shelf tracking system (Mavic Pro drone with controller, Iphone 8 and 11, one AirTag). (B) Mount support for Iphone. (C) AirTag.

In this system, we set up the AirTag acting as a transmitter of Bluetooth and UWB signals. The Iphone 8 is physically attached to the drone and works as 1) a receiver of the AirTag's Bluetooth signals and 2) a transmitter of the tag coordinates to the cloud. The Iphone 11 works as 1) a receiver retrieving the coordinates from the cloud and 2) a receives of the AirTag's Bluetooth and UWB signals (Figure 2). The AirTags do not obtain locations using GPS technology, but working through the network from other anonymous iOS and iPadOS devices nearby. Therefore, the AirTag needs to find the nearest Bluetooth-enabled device and take the device's location data in order to work. The Iphone 8 needs Global System for Mobile (GSM) coverage in order to be able to send the location to the cloud. We chose Iphone model 8 because the type Bluetooth version 5 incorporated in these models offers data transmission speed up to 50 Mb/s. To set up the system, it is necessary to link the AirTag to an Iphone handled by the researcher. To use the UWB technology

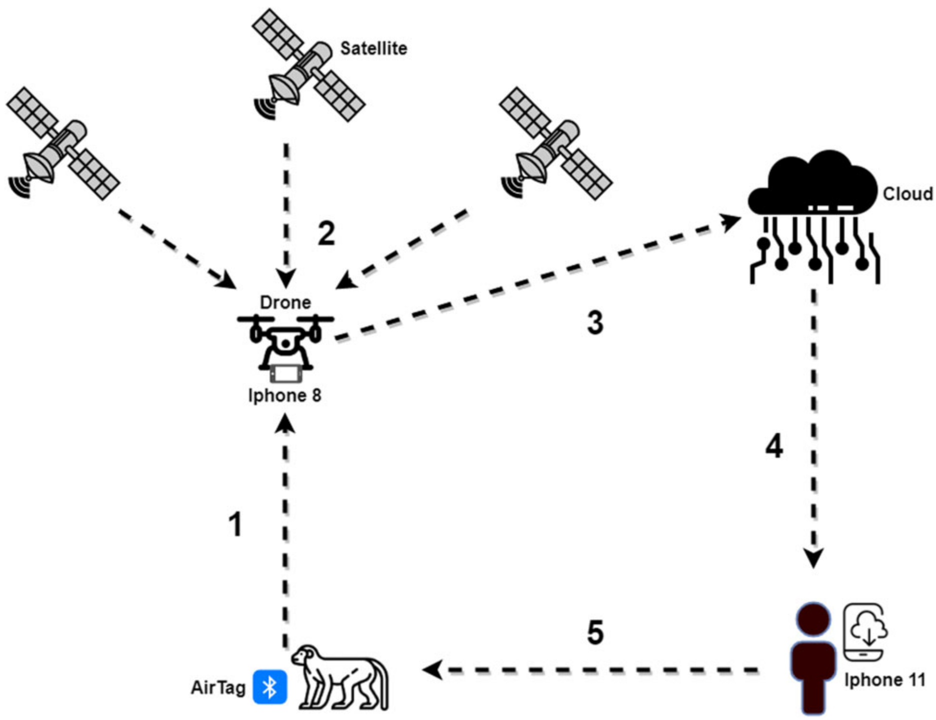

Figure 2. Off-the-shelf tracking system working scheme: 1. Bluetooth signal transmitted by the Airtag; 2. Reception of the Bluetooth signal from the AirTag and the signal from the satellites by the triangulation system; 3. Sending coordinates by triangulation to the cloud; 4. Cloud server sends coordinates to the iphone previously linked to the Airtag. 5. Researcher initiates the searching of the AirTag using Bluetooth and UWB.

(Figure 2; step 5), it is necessary that the Iphone model has the same U1 chip present in the AirTag, so we recommend the use of iphones 11 or newer. Once the AirTag is linked to the Iphone, the "Lost Mode" function must be activated within the "Find" application of the Iphone. After this configuration is set up, the Iphone 11 becomes the device that will receive the coordinates of the AirTag from the cloud. The Iphone 8 attached to the drone will receive the Bluetooth signal transmitted by the AirTag and it will transmit the coordinates to the cloud (Figure 2; Steps 1–3), which will be retrieved by the Iphone 11 linked to the AirTag.

Parameter control flights

Before starting the tracking flights, we carried out 20 flights tests to define the maximum flight altitude that allow receiving the tag's Bluetooth signal. The first step is checking if both smartphones are withing GSM coverage, which can be done sending and receiving data between them. We performed the drone take-off with the Iphone 8 attached to it at minimum distance of 200 m from the tag in an open, non-urban area, with no physical barrier between the drone an the tag. We flew the drone ascending to an altitude of 120 m AGL (above ground level), which is the maximum allowed by the local legislation (ANAC, 2017), and then flew horizontally toward the tag until the drone was positioned over it. We made de drone descend vertically at a maximum speed of 1 m/s until the Bluetooth signal sent by the tag was detected by the Iphone 8 and the coordinates information received by the Iphone 11 from the cloud. We performed the above procedure five times and considered that the maximum detection altitude was the average value obtained ($\bar{x} = 52.8$ m). With this average altitude, we performed five horizontal approach flights at a speed of 5 m/s and we also obtained the average value ($\bar{x} = 50.4$). Considering the average values obtained, we subsequent flight tests in open environments at an altitude of 50 m AGL. We repeated the same procedure in forest environments and obtained average altitudes ($\bar{x} = 32.6$) in vertical flights and ($\bar{x} = 30.4$) in horizontal flights and chose therefore to perform the subsequent drone flight tests at an altitude of 30 m AGL.

Drone flights tracking

We tested the off-the-shelf tracking system design in 2 habitat types: savanna and forest areas, both within the Cerrado biome. The tests were carried out in August 2021, in 2 areas adjacent to Chapada das Mesas National Park, Maranhão, Brazil (Figure 3). Flights were carried out in the savanna area within the "cerrado stricto sensu," typical physiognomy of savanna with forest cover below 30% and in the forest area, within the "Cerradão", a physiognomy that has dense vegetation cover and predominant arboreal strata (Sawyer et al. 2017).

In both areas we carried out two types of experiments: stationary and in motion. For stationary experiments, we placed the tags randomly on the ground in the study area. For the tests in motion, a researcher walked randomly in the study area holding a tag at 1 m above the ground. In all tests, the take-off was done 200 m away from the perimeter of the study area, with the pilot unaware of the tags' location. Lawnmower pattern flights were performed covering the 10-hectare using the Dronedeploy free version software (https://www.dronedeploy.com/). In the savanna, we performed flights at 50 m AGL, with 60% front and side overlap, 5 m/s flight speed, and the "terrain awareness" app function activated. In the forest, we performed flights at 30 m AGL, with 50% front and side overlap, 5 m/s flight speed, and "terrain awareness" app function activated. On each of the tracking flights, the tags were placed at different locations inside the study area. We carried out flights between 08:00–09:30 h and 16:00–17:30 h local time and under the same environmental conditions as the parameter control flights. For the

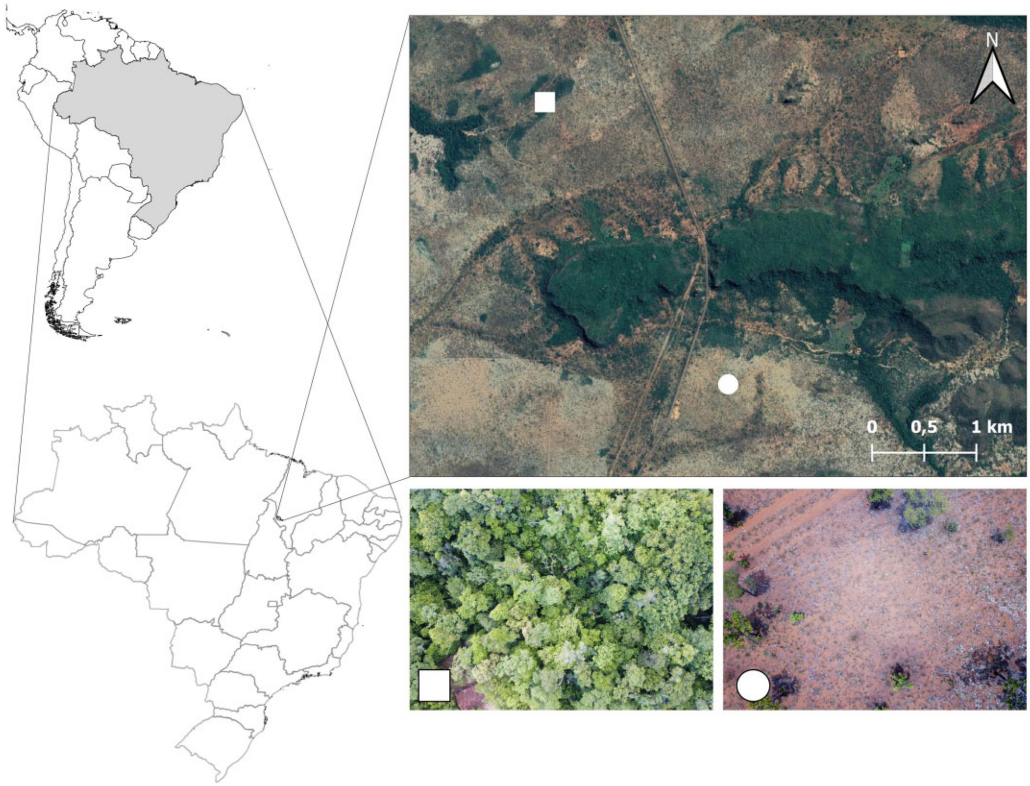

Figure 3. Location of drone tracking flights test areas. Cerradão (white square) and cerrado sensu stricto (white circle).

execution of the lawnmower pattern flight, once the Bluetooth signal was identified by the smartphone coupled to the drone and we confirmed it was sending the coordinates to the smartphone with the researcher, the pilot disabled the automatic flight mode and enabled the manual flight mode to try keeping the captured Bluetooth signal. At that moment, the researcher, without knowledge of the location of the tag, handling the Iphone 11 previously linked to the tag and with the "Lost Mode" activated, started the process of terrestrial tracking of the tag as instructed by the Maps application in the smartphone (Apple Inc.). During the search process, when entering the Bluetooth coverage radius, ± 50 m in open areas, and ±30 m in forest areas, the smartphone starts to consider the origin of the Bluetooth signal and not the location received by the cloud. Once inside the coverage radius of UWB technology, ±10 m, for both types of environments, the smartphone automatically changes the tracking form to directional search with centimeter accuracy (Figure 4).

Figure 4. Accurate search process by UWB technology in Iphone application.

Data analysis

Considering that this off-the-shelf system indirectly involves the use of GNSS, we measured the system's effectiveness based on the two main steps in the overall operation of satellite telemetry units: Fix acquisition and Data transfer (Hofman et al. 2019). Adaptively, we consider Fix acquisition as steps 1–3 (Figure 2) and Data transfer as step 4. Acknowledging that there may be a failure or delay between steps 3 and 4 due to the GSM signal of both smartphones, we considered it an effective detection when the sending of coordinates in step 4 was performed while the drone was still in flight. Considering the average fix acquisition rate of 66% found by Matthews et al. (2013), we calculated detection probabilities above 70% using the binomial test considering the proportion of total detection, by type of environment and type of experiment.

To find out if there is any significant association between the factors environment and the type of experiment that may influence the system's detection capacity, we performed a GLM (Generalized Linear Model) using a binominal distribution and a logit link function with the interaction between the 2 factors. The model selection process was done using the R "drop1()" command, which drops one explanatory variable at a time and applies an analysis of deviance test each time. The significance of the factors was assessed using command "Anova ()." The heterogeneity of residuals was assessed by visual examination of the figures. GLM models with no random factors were fitted using the "glm()" function. In all stationary tests, we recorded the coordinates of the tags using a GPS Garmin eTrex 30×. To calculate the static accuracy, that is, the distance between the GPS coordinates and the coordinates obtained by the off-the-shelf tracking system, we used the formula based on the Spherical Law of Cosines:

$$\text{acos}\Big(\sin(\text{lat1}) * \sin(\text{lat2}) + \cos(\text{lat1}) * \cos(\text{lat2}) * \cos(\text{long2} - \text{long1})\Big) * 6371.$$

We used the *t*-test to compare the mean values of accuracy obtained in the savanna and forest areas. For model validation, we tested for normality (Shapiro–Wilk) and set the significance level at 0.05. All statistical analyzes were performed using R Studio version 1.4.1 (R Core Team, 2019).

Results

We performed 40 tracking flights with the off-the-shelf tracking system, 20 in savanna and 20 in forest, totaling 9.23 flight hours (Table 1). Tracking flight times varied between 5 and 22 min ($\bar{x}$ = 13.85 ± 6.07), from take-off until obtaining the first tag coordinate. Due to the lower altitude and lower detection rate, the total time of flights in the forest area was 6.45 h, while in the savanna area it was 2.78 h.

After conducting all steps illustrated in Figure 2, we obtained an overall detection rate of 65% (90% in the savanna area and 40% in the forest area). The probability of detection above 70% was only significant in the savanna (binominal test, $P = 0.035$). The interaction between environment and type of experiment factors did not significantly influence the system's detection rate ($\chi^2_1 = 0.23$, $P = 0.63$). However, the detection rate of the system was higher in the savanna (90% detection) than in the forest (30% detection, $\chi^2_1 = 12.0411$, $P < 0.01$), while no significant differences were observed between tests in motion (60% detection) and static tests (70% detection, $\chi^2_1 = 0.6099$, $P = 0.43$). In the stationary tests where there was detection, we calculated a mean spatial accuracy of 14.61 ± 0.53 m ($N = 14$) based on the R95 parameter (Figure 5). In the savanna area, the average spatial accuracy was 10.53 ± 1.53 m ($N = 9$), and in the forest area was 13.06 ± 1.73 m ($N = 5$), and there was a significant difference on the spatial accuracy obtained between the two environments ($t_{12} = 2.818$, $P = 0.015$; Figure 5).

Discussion

Finding ways to make wildlife tracking easier and less expensive is a constant challenge for researchers. In this study, we propose a user-friendly system combining drones, smartphones, and tags using Bluetooth and UWB signals that could be potentially applied for animal tracking. To our knowledge, this is the first attempt to use an off-the-shelf tracking system with drones, Bluetooth, and UWB technology.

We found the off-the-shelf tracking system tag detection rate was higher in savanna areas (90%) than the average rate of 66% found by Matthews et al. (2013) for several Australian mammal species and similar to the 85% rate obtained by Hoffman et al. (2019), who analyzed the performance of satellite telemetry units in terrestrial wildlife research across the globe. On the other hand, the detection rate in environments with forest cover was low, with a detection rate of 40%. This is likely due to the vegetation biomass of the trees which blocks the transmission of the Bluetooth signal. In step 5 of all tests, after receiving the tag coordinates via cloud, the researchers, in addition to using Bluetooth and UWB technology, used the tag's sound emission function, demonstrating that this technology can offer a differential in the wildlife tracking process in the precision search, mainly for small animals with cryptic behavior and in forest areas where the animal can be camouflaged below vegetation. However, the sound emission by a tag attached to the animal would be likely to cause disturbances in animal behavior that have not yet been analyzed.

The off-the-shelf tracking system accuracy around 12 m is higher than lightweight GPS collars accuracy averaging 30 m (e.g., used for research on common brushtail in suburban environment, Adams et al. 2013). When compared with the few studies that developed a

Table 1. Drone flights tracking data

Flight	Type	Environment	Detection	Flight time (min)	Accuracy (m)
1	Stationary	Savanna	Yes	9	11,60
2	Stationary	Savanna	Yes	13	8,10
3	Stationary	Savanna	Yes	8	11,91
4	Stationary	Savanna	Yes	10	11,87
5	Stationary	Savanna	Yes	7	9,79
6	Stationary	Savanna	No	13	—
7	Stationary	Savanna	Yes	5	9,84
8	Stationary	Savanna	Yes	7	12,13
9	Stationary	Savanna	Yes	9	8,48
10	Stationary	Savanna	Yes	8	11,12
11	Stationary	Forest	Yes	18	10,48
12	Stationary	forest	Yes	14	13,19
13	Stationary	Forest	No	21	—
14	Stationary	Forest	No	20	—
15	Stationary	Forest	Yes	19	14,67
16	Stationary	Forest	Yes	18	12,38
17	Stationary	Forest	No	21	—
18	Stationary	Forest	Yes	17	14,58
19	Stationary	Forest	No	21	—
20	Stationary	Forest	No	20	—
21	In motion	Savanna	Yes	10	—
22	In motion	Savanna	Yes	7	—
23	In motion	Savanna	Yes	7	—
24	In motion	Savanna	Yes	5	—
25	In motion	Savanna	Yes	8	—
26	In motion	Savanna	No	13	—
27	In motion	Savanna	Yes	7	—
28	In motion	Savanna	Yes	5	—
29	In motion	Savanna	Yes	10	—
30	In motion	Savanna	Yes	6	—
31	In motion	Forest	Yes	15	—
32	In motion	Forest	No	21	—
33	In motion	Forest	No	21	—
34	In motion	Forest	No	21	—
35	In motion	Forest	Yes	16	—
36	In motion	Forest	No	22	—
37	In motion	Forest	Yes	18	—
38	In motion	Forest	No	21	—
39	In motion	Forest	No	22	—
40	In motion	Forest	No	21	—

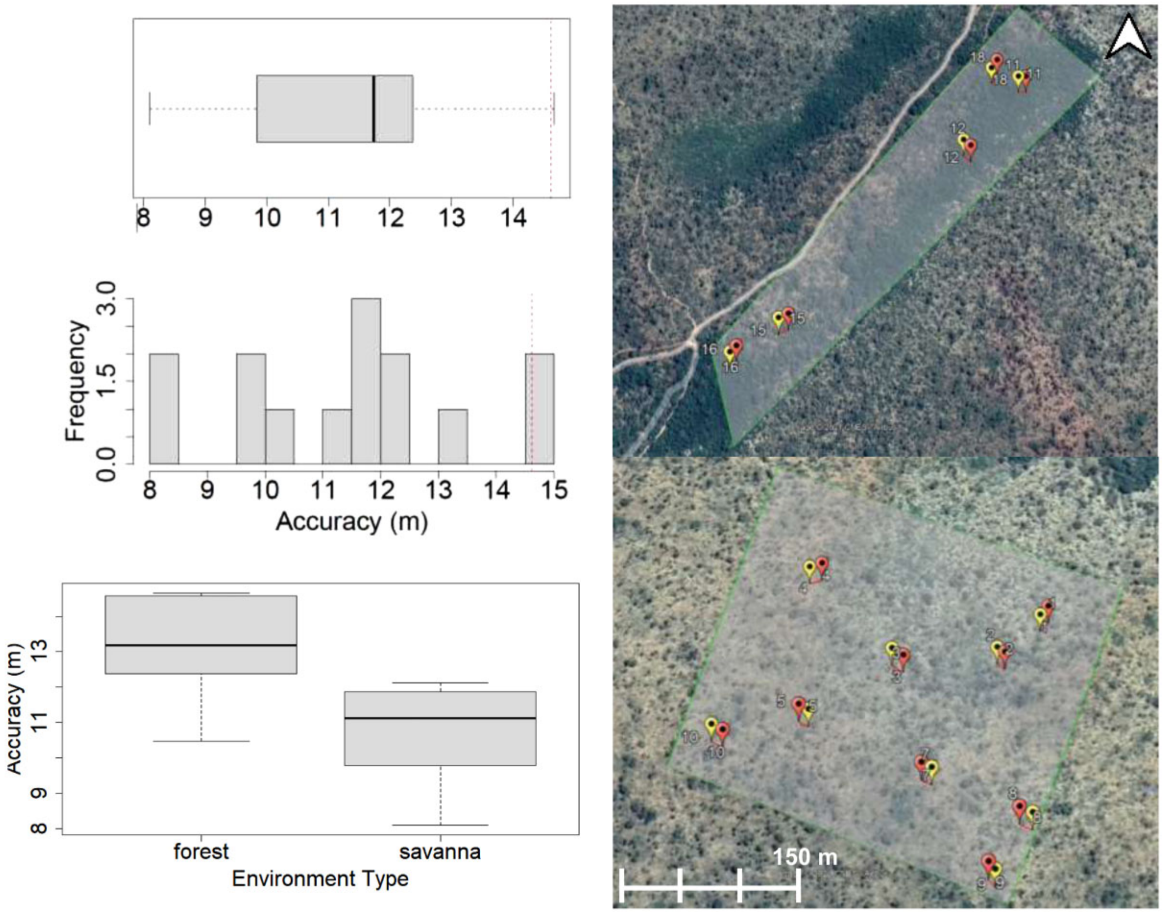

Figure 5. Spatial accuracy of stationary tracking tests in the forest and savanna environments. Flight numbers and the differences between the real and obtained location are shown on the right hand side.

tracking system involving UAVRTS such as Nguyen et al. (2019), with an average precision of 22.7 m, Cliff et al. (2018) with 51.4 m and Hui et al. (2021) with 25.9 m, we note that the accuracy of the system assembled in this study were more accurate (14.61 m). Also, as opposed to the UAVRTS from Cliff et al. (2018), Nguyen et al. (2019), and Hui et al. (2021), in the system we propose there is no need for the development or customization of hardware or algorithms since all parts of the system can be purchased commercially and ready to use. However, we emphasize that the comparison of accuracy of this system with other tracking systems based on radio frequency (UHF/VHF) is only valid within the context of the experiment, since the calculation of the position in radio frequency is done through an estimate of quadratic regression based on the number of "pings" and on the shape of the UHF/VHF signal (Desrochers et al. 2018), while the positioning via GNSS works through the triangulation of satellites (Hofman et al. 2019).

This off-the-shelf tracking system, although using Bluetooth and UWB as its differential technology, has application characteristics that are similar to radio frequency and GNSS telemetry systems. As with radio frequency tracking systems, there is a need for a field search for the tagged animals. And just as in GNSS telemetry, this system depends on the satellite triangulation system, but with the limiting factor of needing GSM coverage. On the other hand, the field effort needed for this system when compared with the traditional radio frequency technique may be lower, as it reduces the need for the researcher to travel by land, and can also enable an increased search coverage depending on the flight capacity of the drone used. The difference in cost between GPS tags with similar size and the tags used in this system is another aspect to be taken into account. While an AirTag can be found for $29, GPS-tags of similar sizes can cost up to $2,000 (Lahoz-Monfort et al. 2021). In addition, its 1 year battery life and its 10 g weight would allow the tracking of any animal with a minimum weight of 350 g, considering the recommended limit of not exceeding 3–5% of the animal's weight (Kenward, 2001). The reduced size and weight of Air tags allows attaching them to different types of animals, and can be attached as a necklace on mammals, or fixed as a backpack on some species of birds and reptiles. Considering that AirTags have IP67 water resistance (IEC 60529), it may not be necessary to include protective structures, although they are recommended for animals with aquatic habits, since the time span that the tag can tolerate water is limited to 30 min at a maximum depth of 1 m. In cases where the tags need to be fixed by protection structures, such structures should not significantly affect the emitted Bluetooth and UWB signals since these technologies do have higher bandwidth than most narrowband signals and are usually only affected by other electromagnetic sources within the same communication channel.

Although we used a specific drone model in this off-the-shelf tracking system, the lack of hardware customization allows the use of different parts of the system (smartphones and tracking devices) on different drone platforms, paying attention to the due previous parameterizations of speed and altitude that will allow the connection of the Bluetooth signal. Different multirotor platforms or even fixed-wing platforms such as the Asa-Branca I model (Mesquita et al. 2021), developed for use in the study of biodiversity conservation in large areas, could be incorporated into this system, thus increasing the tracking coverage area. Another potential modification of the system that does not affect the functioning core is changing the types of smartphones and tags, thus paying attention to the latest Bluetooth class and versions. In this study, we used Apple branded smartphones and tags due to prior availability of the devices for the researchers. However, other brands like Samsung have smartphones and tags with the same type of operation and capacity. Considering that a single tag of this system can be tracked by different smartphones, since the system works in a type of a network, we envisage the possibility of using more than a single drone or even a drone network with attached smartphones in order to locate different targets in an area, making the tracking process possibly more efficient.

Although we demonstrated the feasibility of this off-the-shelf tracking system on controlled targets in savanna areas, we acknowledge that tests on animals can present variable results, whether due to the complexity of the behavior of different species or the different ways of fixation and positioning of tags on animals. Therefore, carrying out new experiments with this system in real animals will help to understand the actual possibilities of use. In addition, further research is still needed for assessing the effects of other operational parameters (flight speed, altitude, flight types, and tag displacement speed) as well as the environmental influence (vegetation types, relative air humidity, and arboreal stratum height). Determining which factors may influence the detection capability of this system could make it more useful not only in savanna areas but possibly in other areas with higher forest cover.

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Conflict of Interest

The authors declare that they have no competing interests.

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