HAL2016-02: Developing a Quadcopter and Infrared Camera System to Monitor and Track the African Forest Elephant (*Loxodonta Cyclotis*)

February 23rd, 2016

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Project Description

In an effort to help combat the alarming decline of African forest elephants, the Humans and Autonomy Laboratory is partnering with the Nicholas School of the Environment, The Elephant Sanctuary in Hohenwald, Tennessee, and the Agence Nationale des Parc Nationaux in Gabon to design and develop a low-cost, mobile airborne elephant monitoring and tracking system. Current state-of-the-art methods of estimating elephant populations rely on counting dung piles; however, these methods are known to be imprecise and labor-intensive. Our system, which uses a quadcopter, custom infrared camera, and tablet-based ground control station, will give conservationists a direct method of counting elephants, as well as monitoring their behavior non-invasively.

Unlike other drone conservation systems, our system has both daytime and nighttime capabilities, allowing conservationists to observe the behavior of the African forest elephant at all hours of the day. In addition to the on-board hardware, the system includes a user interface design component for developing an easy-to-use ground control station that is displayed on a tablet, making the system light and portable, as well as accessible to a wide population of users. The interface is designed such that users with little technical experience can designate waypoints for the quadcopter to circle, capture video, and return to the pre-designated home location. By arming local conservationists with this new technology, they will be able to more directly monitor the behavior of forest elephants and more accurately estimate population numbers. The system could also be implemented into anti-poaching efforts during the night hours when poachers are difficult to locate. The use of a drone instead of manpower to search for poachers reduce the risk for harm to the ecoguards and allows the ecoguards to cover area more rapidly.

Trip Purpose

This initial trip from 2-9 January 2016 to Rèserve Prèsidentielle de Wonga Wonguè, Gabon was to present the Agence Nationale des Parcs Nationaux (ANPN) and Rèserve Prèsidentielle de Wonga Wonguè ecoguards with a wildlife monitoring system using an inexpensive (~$1,500) quadcopter and daytime/nighttime video camera. The goal was to spend 4-5 days in the reserve, with two days being allocated for testing the equipment to ensure it was shipped safely, get a feel for the winds and weather conditions in Gabon, and determine the range of the quadcopter with no infrastructure around (a test that is not feasible in Durham, North Carolina). The remaining days were to be used for showing the ecoguards the capabilities of the system, both during the day and at night, and to train them, such that once we left, they would be able to use the system with ease.

Training of the system would compose of a walkthrough of the quadcopter itself, the user interface, and controls. After training, the ecoguards would have the opportunity of using the system to video elephants, with the Duke team present, to ensure that there they had mastered the use of the system. Wonga Wonguè was chosen as the reserve to launch the initial system due to the abundance of forest elephants that can be seen in the savannah during dusk, as well as the forest/savannah mosaic that allows for safe launching of the quadcopter. With this system, it is our hope that the ANPN would have the capability of launching an aerial video recording system that can be used for anti-poaching efforts and elephant population estimations.

System Overview

The wildlife conservation system can be broken into three components: 1) The quadcopter, 2) The video equipment, and 3) The ground control station. Each of these components is vital to having a fully implemented system that the ecoguards can use to monitor the African forest elephants in Wonga Wonguè.

The quadcopter that was chosen for this system is the 3D Robotics IRIS+. The IRIS+ was selected for its cost ($600), ease of repair in the event of a crash, and ability to be controlled by an open source application called Tower that was released by 3D Robotics. The IRIS+ quadcopter has a maximum flight time of 15 minutes with the full payload of the infrared camera and the GoPro Hero 4. Figure 1, below, gives an image of the IRIS+.

Figure 1 - 3D Robotics IRIS+ Quadcopter

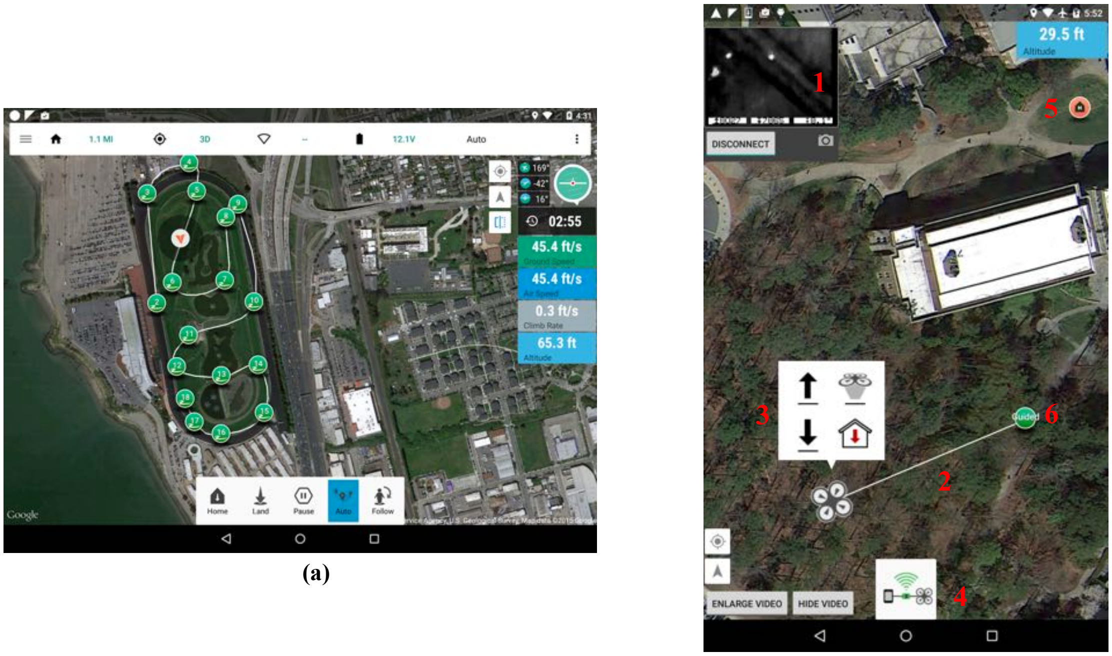
Video Equipment

Since the system should have the capability of flying both day and night operations, there are two cameras onboard the IRIS+. The daytime footage is captured using a GoPro Hero 4 that is mounted via a gimbal to the front of the IRIS+. All footage from the GoPro Hero 4 can be stored onboard the IRIS+ while recording on a micro-SD card. The night camera is an infrared sensor that captures the gray scale heat signature of the objects within the environment that is in its frame. The sensor that is used is a FLIR Lepton DroneThermal infrared sensor that transmits a live feed of the infrared video to the ground control station. Figure 2 shows an image of the infrared sensor that is mounted on the bottom of the IRIS+.

Figure 2 – DroneThermal infrared sensor

Ground Control Station

The ground control station is a tablet-based application called Tower that is an open source mission planner developed by 3D Robotics for the IRIS-series. The original version of Tower, which can be seen in Figure 3(a), has several features that are confusing and provide little assistance in mission planning, such as roll, pitch, and yaw and ground/air speeds. In order to reduce the complexity of the user-interface, several modifications were made that made the overview less cluttered and better suited for the purpose of wildlife monitoring. Figure 3(b) shows the modified user-interface of Tower. There are three main changes that should be noted in the modified version of Tower. The first is the infrared camera video feed box in the upper left corner of the map. A live feed is transmitted to the Tower application from the IRIS+, which is essential for night missions due to the lack of visibility. The second major modification is the reduction of buttons and indicators from the original version of Tower. The roll, pitch, and yaw indicators have been taken out, as well as the air/ground speed indicators. The tool bars have been greatly simplified and compressed to allow more map to be shown to the user. Finally, the commands for the drone have been moved from the bottom of the screen and now appear next to the drone as it moves throughout its waypoints. The controls can be hidden/displayed by clicking the drone icon. Missions can be uploaded, stored, and retrieved inside of Tower and uploaded to the IRIS+. In addition, an altitude profile has been implemented such that the user can preprogram the altitudes at which he/she desires the IRIS+ to operate at along its waypoints.



(a)

(b)

Figure 3 – (a) Unmodified version of Tower user-interface from 3D Robotics (b) Modified Tower user-interface with (1) Infrared camera video feed (2) IRIS+ trajectory (3) IRIS+ controls (4) Tablet/IRIS+ connect button (5) Initial launch location (Home) (6) Waypoint

Field Observations

Below gives a detailed breakdown of the four days that the team from Duke University spent at Rèserve Prèsidentielle de Wonga Wonguè, Gabon. Two of the days were spent conducting initial tests of the equipment, one day was spent debugging calibration errors and repairing the IRIS+, and the final day was spent in the field monitoring the elephants in the daytime.

Day 1 (January 4, 2016)

Midday on Monday, January 4, 2016, the team from Duke University took a three hour boat ride down the coast of Gabon to get to Rèserve Prèsidentielle de Wonga Wonguè. After arriving to the perimeter of Rèserve Prèsidentielle de Wonga Wonguè, we took a 2.5 hour ride by trucks through the forest/savannah mosaic to the main camp. It was clear on the ride through the reserve that Wonga Wonguè would be an excellent place to launch the version 1.0 of the system due to the vast savannahs and amount of wildlife, such as forest elephant and buffalo, that freely roamed in and out of the forests. Figure 4 shows an image of a forest elephant that was roaming the savannah next to camp when we arrived. The proximity of the elephants and buffalo to the roads also proved to be promising for the IRIS+/ground control station communications. Going into the trip, we knew that there would be a limit to the distance in which we could send communications to the IRIS+ from the tablet, but were unsure as to what that distance was when no buildings were around or other radio waves that could interfere with the signals.

Figure 4 - Forest elephant along the tree line of the savannah and forest

Upon arrival to the Rèserve Prèsidentielle de Wonga Wonguè main camp, on the afternoon of January 4, 2016, an inventory was taken of all the items that were shipped from Durham, NC (IRIS+, spare parts, tablets, tools, etc.). After determining that all items had arrived safely, we tested each of the three quadcopters for GPS-lock and wired each of the infrared cameras to ensure the transmitters were working appropriately and that the tablets were receiving the video feed. Initial tests to for GPS-lock and infrared camera video transmission all worked. After each of the components were sorted and initial tests were completed the team decided to plan for flight testing the next day at camp, which would allow for time to gather data for how far the ground control station tablet could communicate to the IRIS+.

Day 2 (January 5, 2016)

The second day at Wonga Wonguè was allocated for flight testing with each of the three quadcopters and determining the maximum distance in which the ground control station tablet could send communications. One side of the camp had an overlook of a savannah that had a line of sight length of approximately 640 meters, which proved to be ideal for flight and communication distance testing. Each of the three quadcopters were tested and ranked in reliability and stability for the environmental conditions of Wonga Wonguè. The most reliable IRIS+ had a maximum communication distance of approximately 320 meters before returning to the takeoff location. Based on the observations of the wildlife in Wonga Wonguè from the previous day, it was determined that this maximum communication distance would be ample in flying missions.

In addition to determining the maximum communication distance for the IRIS+, the team also had to verify GPS reliability and ground control station map alignment. Numerous flight tests resulted in the acquiring of a least 8 satellite signals (a minimum of 4 satellite signals is required for 3D GPS), thus we knew that GPS should not be an issue. Once GPS reliability was established, we had to finalize the user-interface map tiles such that they were aligned to GPS coordinates. To do this, we went to several random locations within the reserve and gathered GPS latitude and longitude data using our iPhones and recorded them onto the ground control station. Using these locations, we were able to align the map tiles on the user interface to match our location. Figure 5 shows two images of the maximum communication distance and GPS testing.

(a)

(b)

Figure 5 – Flight testing at camp to determine maximum communication distances and GPS reliability. The red circle indicates the IRIS+ quadcopter mid-flight

During flight testing, one of the IRIS+ crashed and had to have replacement propellers installed. While the crash did not seem to be too harmful to the drone, we still went through the protocol of flight testing after repairs. During these tests it was determined that this particular IRIS+ had a problem with returning to the correct location after completing its mission. The IRIS+ landed several meters to the right of the initial launch point. Once determining this, we decided to use this drone as a backup for the duration of the trip since the uncertainty of returning to the launch point was unpredictable. The other two IRIS+, however, launched, completed the designed missions, and returned to the launch point successfully.

After a day of flight testing and map tile alignment, we were lucky enough to have a close encounter with two forest elephants in the camp at night. Two forest elephants wandered into the camp at approximately 10:00 PM and stayed for over an hour. As can be seen in Figure 6, we were able to stand above the elephants and observe their behavior at night. We learned that, during the night, the elephants are not bothered by the presence of humans or foreign noises. This provided promise that night operations would be the optimal choice for this system since there is a lower chance of the elephants retreating back into the forest due to the noise/presence of the IRIS+.

Figure 6 – One of two forest elephants in the camp during the second night

Day 3 (January 6, 2016)

After a successful day of flight testing, the team decided to take the system to a location in the reserve that has a large watering hole and, typically, serves as a gathering location for several buffalo and forest elephant. This location had the perfect layout and topography for the initial test of the system with the wildlife since the watering hole was in a valley and we could launch from the hills surrounding. This provided us a perfect vantage point to observe the behavior of the IRIS+ with the wind and the wildlife when the IRIS+ got close. On this particular day, there were several water buffalo gathered along the shore of the watering hole, which proved to be great test subjects for the first launch.

A total of four missions were preplanned and launched at the watering hole, each with successful takeoffs, trajectory following, and landings. However, it was during these flights that we learned how timid the buffalo were in reaction to the noise from the IRIS+. In each attempt to fly the IRIS+ over the herd, they scattered quickly. This provided insight into how high the altitude profiles should be set for future missions. Although no wildlife were captured on camera during these missions, they were still deemed successful flights since the IRIS+ completed its mission autonomously and returned to the precise launch point even with wind interference. Figure 7 shows an image of one of the IRIS+ flying a mission at the watering hole.

Figure 7 - IRIS+/GoPro camera testing

The successful missions that were flown the morning of Day 3 gave the team confidence to take the system on its first full test with the ecoguards that afternoon. These were also to be the first tests with forest elephants, since forest elephants can be seen more frequently out in the savanna during the afternoon and at dusk. Some of the forest elephants had been collared in the months prior to our arrival to the reserve, so we had an idea as to where a few of the elephants were located in the park. The data, while not real time, did provide some information as to a general location to begin searching for the elephants. The search to find elephants only took approximately 15 minutes. Once two elephants were located the team quickly readied the IRIS+ for launch (Figure 8). As an initial test, Tower was not to be used for preplanning a mission. We thought it better to use the standard remote controller from 3D Robotics to ensure that the IRIS+ was operating correctly.

Shortly after launch, we began having error alarms from both the drone and the controller that we had not heard before. After numerous attempts to re-launch the IRIS+, we determined that we had to return to camp to debug the unknown errors. After several hours of debugging and testing, it was determined that all of the IRIS+ quadcopters had RC calibration errors. This came as a surprise to all of us since the drones were working fine a few hours prior and all had randomly started giving RC calibration error warnings. Since there was limited satellite Wi-Fi at the reserve and the team before had not seen this error it took several hours (even into the next day) to recalibrate the controllers for each of the drones. A debugger released by 3D Robotics called Mission Planner, was installed and used to assist in the recalibration of each of the controllers and IRIS+. This RC calibration error set the team back a full day that was originally going to be used for training the ecoguards and flying night missions.

Figure 8 - Initial flights with the ecoguards

Day 4 (January 7, 2016)

The morning of the final day at Wonga Wonguè was spent calibrating the controllers for each of the IRIS+ and conducting test flights. After approximately 4 hours of debugging and installing mission planner, the team had each of the IRIS+ calibrated and ready for flight testing. However, when we installed a LiPo battery on one of the IRIS+ it immediately caught fire. After multiple attempts to stop the IRIS+ from catching fire we finally decided to strip the drone of all its parts to use for the remaining two IRIS+ in the event of additional crashes. The remaining two IRIS+ were successfully tested, so the team set out into the reserve with the ecoguards to demonstrate the system's capabilities. Since we were operating in the mid afternoon there were several forest elephants and buffalo wandering the savannah for us to monitor. Figure 9(a) shows an image of the drone hovering over one of the forest elephants along the forest tree line. While most of the elephants and buffalo retreated into the forest due to the noise coming from the IRIS+, these elephants were surprisingly calm while the drone was hovering over them. After a successful return to the launch location the team changed the batteries and prepped the IRIS+ for another launch with two different forest elephants. This time, however, the wind gusted and an updraft carried the IRIS+ outside of the maximum communication distance of the controller. After numerous attempts of recalling the IRIS+ back to the launch location it was determined that the drone was not able to receive communications. The team waited for approximately 20 minutes after communications were lost (well beyond the maximum flight time of the IRIS+) to see if the IRIS+ would return but it did not. This left the team with one remaining system. Two tests were completed with the remaining system. Figure 9(b) shows an image of two of the elephants that were captured running across one of the valleys of the savannah. A screenshot from the final flight can be seen in Figure 9(c). During this final flight, one elephant was caught before dusk in the savannah. The IRIS+ is hovering at an altitude of 150 feet during this mission and the elephant can be seen inside the red circle.

(a)

Since only one system was fully intact after the four days of testing in the reserve, it was decided that the team bring the system back to Duke University and continue development. We are currently researching what should be done about the design in terms of noise and minimizing disturbances.

A short video compilation of the trip can be seen here:
https://drive.google.com/file/d/0B4FKFMEYeV2VazlVOVhfQ2ZBYXM/view?usp=sharing

(b)

(c)

Figure 9 - Images from daytime GoPro footage. (a) IRIS+ (red circle) flying over a forest elephant (blue circle) near the tree line. (b) Two elephants running across the savannah during video capturing. (c) One forest elephant (red circle) captured by the GoPro.

Conclusion

The trip to Rèserve Prèsidentielle de Wonga Wonguè, Gabon provided insight into how this system would assist the ecoguards, ensured that the proof of concept is not far from being developed into a final product, and provided a testing environment that led to many lessons learned that would be difficult to predict in the United States. While we were unable to test the system at night with the infrared camera, we were able to gather daytime footage of both forest elephants and buffalo. The noise from the IRIS+ did cause many elephants and buffalo to retreat into the forest, possibly due to the noise being similar to that of a swarm of bees, therefore, further research is needed to determine what frequencies disturb elephants and buffalo. We also received very insightful feedback from the head of the ecoguards as to what applications he would find this system useful for. In addition to the monitoring of the forest elephant, he stated that the system could be used to patrol the coast of Wonga Wonguè to determine if any illegal fishing is occurring offshore. The boats that illegal fishermen use are difficult to spot at night, but with the use of the infrared camera, locating them would be simple.

Figure 10 - Humans and Autonomy Laboratory members with Rèserve Prèsidentielle de Wonga Wonguè ecoguards

Lessons that were learned from our trip to Rèserve Prèsidentielle de Wonga Wonguè, Gabon included:

1. The infrared camera sensor components should be housed to reduce the complexity of the connecting the wires.
2. The communication reliability for the infrared camera should be addressed as it can be unpredictable at times
3. There should be a method for storing infrared footage onboard the drone on a micro-SD card in the same method as the GoPro Hero 4.
4. The drone should be exposed to hot (>85 degrees F) and humid (>70%) environments for an extended period of time (>5 days) without any time in the air conditioning.
5. The system can be used for more than just wildlife monitoring. There was high interest in using the system to monitor the coastline for illegal fishing.

These lessons that were learned will be addressed in future conservation efforts on the same platform to continue moving towards a finished system. The main goal of this effort was to design a system that is simple to use, is affordable for ANPN ecoguards' budgets, and gives the capability of both day and night operations. While there was not enough time to address the night operations, we are looking to further develop the infrared camera to increase its reliability and decrease the complexity of its setup. We believe that emerging human/machine systems, such as the one described here, will only make the daily routines of conservationists and ecoguards easier and more efficient. To this end, we will continue to provide assistance to conservation groups, not just in Gabon, but worldwide.

Acknowledgements

The Humans and Autonomy Laboratory would like to thank the Duke Tropical Conservation Initiative (DTCI), the Information Initiative at Duke (IID), the Pratt School of Engineering, and the African Elephant Fund (AEF) for their monetary support of this project. We would also like to thank The Elephant Sanctuary for their intellectual contributions and hospitability for testing the camera equipment. Finally, we thank the Agence Nationale des Parcs Nationaux (ANPN) and the Centre Nationale de la Recherche Scientifique et Technique for permission to conduct the research and for their administrative and logistical support. We also thank David Fine and the staff of the Rèserve Prèsidentielle de Wonga Wonguè for their collaboration and support while in the reserve.