Evaluation of Unmanned Aerial Vehicles and Thermal Imaging for Arboreal Wildlife Surveillance

By

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Abstract

An important component of wildlife management and conservation is monitoring the health and population size of a species. Being able to monitor the population size of an animal group can inform researchers of animal welfare, potential changes in habitat and can be used to inform conservation efforts within a region. Traditional methods of estimating primate densities have been based on field survey techniques with localized multi-observer sweep samples (Whitesides et al., 1988). This method of surveying has historically been a difficult task, requiring a considerable amount of time and resources to get accurate results. This is especially true when attempting to detect and geolocate arboreal primates that live in densely vegetated and in relatively inaccessible habitat areas. Through this study we explored the use of Unmanned Aerial Vehicles (UAV) technologies equipped with thermal imagers to detect and identify arboreal primates using manual and automatic detection techniques. An important result of this study is that for the most accurate target identification, flying at lower altitudes and early morning thermal infrared (TIR) image collection provided the highest level of contrast and produced images that could be used for target analysis. Tests done later in the day or at higher altitudes yielded image sets that did not provide enough contrast to allow for identification of targets. However, even when flying during optimal conditions when using a low-resolution TIR camera, the resulting thermal images are difficult to analyze using automated detection processes based on object thresholding and tended to produce a high level of false positives. Another objective of this study was to determine the applicability and accuracy of applying Structure from Motion (SfM) modeling using thermal images to determine wildlife distance from ground. We found that the spatial resolution of the camera used for testing to date was not sufficient for enabling an adequate number and distribution of image match points to be generated that would yield an accurate elevation point cloud. A composite image using both thermal and RGB imagery was used to create SfM models of the study area, but this did not provide enough information to accurately determine animal location and altitude.

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I would like to take a moment and thank everyone who was involved in this project starting with my advisors both at my home university of San Diego State University and my host university of Carinthia University of Applied Sciences, Doug Stow and Dr. Paulus Gernot. Thank you for putting in the time, energy and for sharing your knowledge to help see this project through.

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CHAPTER 1

INTRODUCTION

1. Rationale

An important component of wildlife management and conservation is monitoring the population size and density of a species. For primates, traditional methods of estimating population densities have been based on field survey techniques and localized multi-observer sweep samples (Whitesides et al., 1988). This method involves multiple ground-based observers walking through a study area and conducting a manual count a species. This process is labor intensive and requires researchers to walk long distances through potentially difficult terrain and vegetation. There is also the potential that observers will not be able to gain accurate species counts as animals are likely to flee from their approach or are located outside of the researcher's field of view. Due to these factors, this traditional method of animal surveying has historically been a difficult task, requiring a considerable amount of time and resources to get accurate results, particularly when attempting to detect and geolocate arboreal primates that live in densely vegetated and relatively inaccessible habitats.

Recent advances in unmanned aerial vehicles (UAVs), thermal imaging systems and machine classification techniques have created the opportunity for ecologists and wildlife scientists to survey larger areas at reduced costs compared to conventional ground-based surveillance methods. Advances in images registration and change detection, such as repeat station imagery (RSI) (Stow et al., 2016) may also lead to an increase in accuracy in animal population estimates when looking at subjects as they are moving through their habitat. The use of UAV technology enables high temporal and spatial resolution imaging which can greatly increase the accuracy of wildlife counts. Previous studies have attempted to determine optimal UAV survey flight parameters (Gonzalez et al., 2016, Oishi et al., 2018, Witczuk et al., 2018) and to develop automated animal detection algorithms (Seymour et al., 2017), however most studies have been focused only on animals in open areas (prairies, savannas, fields, etc.) or aquatic wildlife. Limited research has been conducted on the identification of arboreal, or tree dwelling animals, where canopy cover can limit visibility and impede surveying.

2. Problem Statement and Research Questions

This research is focused on the technical and procedural elements of using UAV-TIR remote sensing to conduct animal surveys. The objective is to develop and trial new technologies and to test and refine current thermal survey methods to achieve greater animal survey accuracy and efficiency in a densely forested area. An additional objective is to explore the potential to estimate the height of arboreal animals above ground level utilizing SfM photogrammetric techniques. As with any study working with animal subjects, the welfare of the species was monitored to limit animal disturbance and prevent undue stress on wildlife and efforts were made to determine what are the best practices concerning animal welfare. The research questions addressed in this study are:

1. What are the flight parameters (flight, flight speed, elevation, etc.) that yield the highest accuracy for arboreal primate detection?
2. Does Repeat Station Imaging (RSI) with both revisit and rapid sequence image capture techniques improve the accuracy of arboreal primate detection?
3. What image processing functions and flow produce the highest accuracy for arboreal primate detection?

4. How accurately can subject elevation be estimated from the ground using TIR data and structure from motion methodologies?
5. How can these low-altitude aerial surveys be conducted to minimize and limit wildlife disturbance?

Chapter 2

Literature Review

1. Traditional Primate Survey Techniques

Population surveys are an important part of primatological research and gives insight into their ecology and behavior and can inform conservation efforts. An estimation of the number of primates within an area or primate community and can help researchers understand what processes limit primate populations, both ecological (available resources) or social (conflict and competition between individuals or primate groups) (Isbell 1991, Wrangham & Chapman, 1993). A knowledge to the density of a species can also be used to investigate how disease is spread within a population (Nunn & Dokey, 2006). Methods of surveying vary and can range from measurements of relative abundance, density of a species in an area, or total population counts. Total population count methods can only be conducted in a relatively small survey area, when the species can be easily identified, the animals to be counted are not greater than 500, and individuals or groups can be distinguished from one another (Plumptre et al., 2013). For study areas that do not meet that criteria, line transects have been the main method used. To conduct a line, transect survey, a series of linear paths are established by the researcher, usually by cutting a path through the vegetation in the study region. This area is then measure and marked to allow for the estimation of animal location in relation to the transect. The conditions for the use of this method are that all animals in the transect line must be detected, animals are detected in their initial location, the target species moves slowly relative to the speed of the observer, the distances from the transect are measured accurately, and each incident of detection is independent event (Burnham et al., 1980; Buckland et al., 1993). These transects are then walked by single observers who have been trained to observe animal species and are familiar with the target's potential response to their approach (alarm-call, patterns of branch crashes, escape maneuvers etc.) This process does require a fair amount of training and there can be a significant difference between surveyors in skill level which can skew the population number and reduce the accuracy of the final count which is problematic when monitoring a species population count over time. Studies have shown that when only using standard line transect techniques, changes in population can only be detected when there are dramatic changes in within the population. Plumptre (2000) demonstrated that line transects techniques will only allow for 10 – 30% change to be delectated between subsequent line transects. By increasing the level of detection per survey this number can be reduced and allow for a closer monitoring of a species. Being able to monitor small changes in a species is especially important when dealing with small populations and endangered species when even minor changes could be cause for concern.

2. UAV and Thermal Imaging Techniques

2.1 UAV Technology

UAVs, also known as Unmanned aerial systems (UAS), drones or remotely piloted aircraft refers to any airborne vehicle with no person onboard with capability of controlling the aircraft (Eisenbeiss, 2004). The use and development of UAV technology was primarily driven by military applications until recently where the increase in technological capabilities and decrease in cost allowed it to be used for civilian applications such as precision agriculture, forestry, hydrology, archaeology and environmental monitoring. The applications of UAV technology are just beginning to be explored for wildlife surveillance. A typical UAV system consists of the UAV platform, sensor payloads and a ground control station.

Within UAV platforms there are two main categories; Fixed wing and multicopter. Fixed wing UAVs are designed similar to more traditional types of aircrafts, such as airplanes, and consist of a central body that has two wings and a propeller system. This style of aerial vehicle can be divided into two types upon characteristics such as size, flight endurance and capabilities (Watts et al. 2012). The widely accepted classes of UAV platforms are; Micro (Miniature) or Nano Air Vehicles (MAV or NAV), small unmanned aircraft systems (sUAS), which is subdivided in low altitude, short-endurance (LASE) systems, low altitude, long endurance (LALE) systems), medium altitude, long endurance (MALE) systems and high altitude, long endurance (HALE) systems (Watts et al. 2012). For the purposes of wildlife surveillance, the most commonly used platform is the LASE sUAS because this system does not require a runway for deployment/recovery and is easily transported which makes it ideal for field work in remote locations. Aircrafts in this category typically weigh 2-5 kg and have wingspans less than 3 meters (Watts et al. 2012). The benefits of fixed-wing UAVs are that they can fly at higher speeds, use less energy and cover a larger area although they typically require a predetermined flight plan without much room for variability midflight.

The multi-rotor aircraft or multicopter consist of a central body and have multiple propellers to facilitate flight and maneuvering of the aircraft. Typically, the UAV has four rotors (quadcopter), six rotors (hexacopter) or eight rotors (octocopter). The advantages of using a multi-rotor in wildlife surveillance is the ability to hover mid-flight, typically a higher payload capacity which allows for a larger range of sensors, the ability to take pictures at any orientation and their greater maneuverability allows it to navigate around obstacles and land in small areas with uneven terrain. When looking at the uses of thermal imagers as the primary sensor payload, the multi-rotor aircraft allows for a more precise control of altitude, speed, and direction which are maintained through system integrated GPS, barometric height sensors and magnetic field sensors. The thermal camera can also be mounted so that panning and manual control can be achieved. An additional consideration is the flight operations to be used in the study. Chabot et al. (2015) divide these operations into two categories, “close-up” and “overflight”. “Close-up” flights are almost exclusively performed by multi-rotor UAV which are flown manually by a ground pilot. This method is used to achieve relatively close-range and low-altitude surveying. The ability of rotary-wing UAV to vertically take-off and land close to subjects, fly slowly and hover in place allows for closer observations of an individual target such as a nest or a single animal. The ability of multi-rotor cameras to be fitted with a remotely adjustable camera, which can be controlled mid-flight, allows the pilot to achieve the optimal viewing angle for the subject to produce targeted images. The other flight operation discussed by Chabot et al. (2015) is the “overflight” which can be flow either using a multirotor or fixed wing UAV. These flights are typically flown using a predetermined flight plan at a higher elevation and is used to survey the abundance or distribution of animals in a given range “Overflights” are generally follow a systematic grid pattern similar to traditional transect-based surveys.

2.2 Thermal Imagers

Thermal imagers were also originally developed by the military with the intended application for detecting and identifying enemy personal and equipment and have since been adapted to civilian uses. Thermal imagers are infrared radiation detectors that can be used for non-contact thermal mapping of emitted infrared radiation (heat). The thermal infrared (TIR) camera produces a thermal image that displays the spatial distribution of the thermal energy being emitted within the scene. An individual object of interest within a scene are denoted as thermal signatures (Havens & Sharp, 2016). The thermal signatures are distinguished from the background of the scene or other signatures by its spatial distribution (size and shape), intensity distribution (temperature) and the spectral distribution (wavelength band of infrared-radiation) (Havens & Sharp, 2016).

These images are created since all objects above absolute zero radiate heat. The amount of heat radiated off these objects is determined by the surface condition and temperature of the object and it is this radiated temperature that is then captured by the TIR camera. This is similar to the way that conventional RGB images are captured but instead of recording visible light, the sensors capture infrared radiation. To record this data, the thermal detectors utilize a material with a temperature dependent property so that when the incident radiation is absorbed the temperature of the material will increase accordingly. This produces a physical change that is measurable, such as an electrical output signal that is a result of the temperature dependence of resistance acting as a thermal transducer. One of the most common types of thermal detector is a Microbolometer due to its low cost and large detector arrays. The microbolometer is a broadband detector which consists of an array of pixels with each pixel consisting of several layers that is isolated from neighboring pixels through a vacuum seal of the detector package. The detector responsivity of the sensor is limited by the thermal conductance of the material used and the speed of response is limited by the thermal heat capacity divided by the thermal conductance. This creates an inverse relationship between heat capacity and thermal temperature fluctuations (noise). A reduction in heat capacity increases the speed but will also result in nosier images. Two of the most commonly used radiation-detecting materials in the microbolometer are α-Si

(Amorphous Silicon) and VO_x (Vanadium Oxide). For the purposes of this study we used the FLIR Duo R which is an Uncooled VO_x Microbolometer that records information on the spectral bands between 7.5 – 13.5 µm with reported accuracy of +/- 5 °C and a thermal sensor resolution of 160x120 thermal resolution. This camera can record both video and still images with a thermal frame rate being 8.3 Hz (PAL). It can also capture RGB images at a resolution of 1920 × 1080.

3. UAV surveying of Arboreal Animals

Research conducted specifically on the detection of arboreal animals has been limited do to the inherent difficulties associated with landscapes with dense tree canopies and foliage which reduce visibility and inhibit detection. The research done using UAVs to detect arboreal animals has sought to overcome these limitations with some success. Gonzalez et al. (2016) examined the use of UAV mounted thermal imaging systems to automatically detect koalas (*Phascolarctos cinereus*) and distinguish them from other wildlife detected within thermal videos. In this study they tested two different algorithms to automatically track and classify wildlife based on image characteristics such as color, size and position. Stark et al. (2017) demonstrated how UAV surveillance and GPS tracking of proboscis monkeys (*Nasalis larvatus*) in Sabah, Malaysian Borneo can be used to aid in conservation methods. Using a fixed winged UAV, they created a high-resolution habitat map and used tracking data collected from a single male proboscis monkey. From this they determined the habitat range for the one-male proboscis monkey group and the effects that deforestation had on the species. Their findings motivated the local government to halt any further land clearing within the range. Matsuzawa et al. (2017) used UAVs for the study of Yunnan Snub-nosed monkeys (*Rhinopithecus bieti*) in Yunnan, China but was primarily focused on small UAV's with first person view abilities to identify primate groups in tree in advance of researchers approaching on foot and did no image processing for the detection or tracking of the monkeys, post data collection. Wich et al. (2016) used UAVs to determine orangutan (*Pongo abelii)* populations using nest counts as population indicators in Gunung Leuser National Park in Sumatra, Indonesia. In their results they found that the UAV was better able to detect high altitude nests then the ground-based observers but missed nests farther below the canopy and overall had poorer results than ground-based observation. Kays et al. (2018) conducted a study using UAV based thermal infrared sensing to identify arboreal mammals such as the mantled howler monkey (*Alouatta palliata),* the black-handed spider monkey *(Ateles geoffroyi)*, and kinkajous (*Ochroma pyamidale)* in Barro Colorado Island, Panama. They found that the thermal infrared camera was able to better detect wildlife higher up in the canopies which are typically missed by an observer on the ground but that overall, a human ground-based counter was better able to identify more animals. They also found that when using thermal infrared data alone it was difficult to identify species and the detection ability was greatly increased when using synchronized RGB imagery.

4. Animal response to UAVs

While showing promise as a new minimally invasive survey method, UAVs also represent a new potential stress to wildlife and have been shown to cause animals to exhibit both behavioral (Pomeroy et al., 2015, Mulero-Pázmány et al., 2017) and physiological (Ditmer et al., 2015, Vas et al., 2015) responses to UAVs that can have negative consequences on animal welfare. The low altitude and loud buzzing noise emitted from a UAV can cause animals to respond in a flight or fight response which can disrupt their natural behavior (Ditmer et., 2015, Pomeroy et al., 2015 Mulero-Pázmány et al., 2017). The effects that UAV flights have on wildlife are highly variable and the impact that UAVs have on a species are related to both the UAVs attributes and flight parameters as well as the animal being researched. In 2014, the U.S National Park Service banned the public use of UAVs within park boundaries after a low-flying UAV Zion National Park caused a herd of bighorn sheep (*Ovis canadensis*) to scatter and lambs were separated from their mothers. Ditmer et al. (2015) studied the influence that UAV flights had on the behavior and physiology of 4 free-ranging American black bears (*Ursus americanus)* in Minnesota. The bears were monitored using cardiac biologgers that remotely monitored the stress response using increases in heart rate in beats per minute as an indicator of stress. Each flight was flown 20 m above the subject and the flight was programmed to hover in place for one minute followed by two, consecutive large (20 m radius) turns and then return to the start point for one minute. Their results found that all bears, including the subjects that were denned for hibernation, exhibited elevated heart rates that increased to as much as 123 beats per minute above pre-flight baseline, while measurable change in movement behavior was only shown in 11.1% of flights. Birds have shown to be more prone to react to UAVs comparted to other taxa. Their response to UAVs is so dramatic that UAVs have been used to scare off birds that are considered to be nuisances in areas like agriculture, fisheries or airport safety. Birds have also been known to attack smaller UAVs. Other factors that impact an animal's reaction to a UAV are proximity, size, time of day, and if the UAV resembles a natural predator of the species.

5. Repeat Station Imaging

RSI is an approach to image capture and processing that limits the registration error between the multitemporal images and enhances target detection though highlighting changes within a scene. RSI captures images over time from the same location in the sky and processes images on a frame-by-frame basis using specific altitude, horizontal coordinates, lens focal length and view angle that are replicated for sets of multi-temporal images (Stow et al., 2016). This is achieved by using GNSS-based triggering systems and autonomous flight systems. This entails relatively high-frequency image capture along flight lines. Sequential pairs of images are registered, and high magnitude image difference anomalies would represent moving targets. Image-to-image registration is completed between corresponding time sequential image pairs for the same station points using an automatic image registration software such as SARA. Both repeat-pass and high-frequency along track images can subjected to this registration processing. Registered image frames are then processed as a temporal layer stack using Agisoft Metashape or similar software to create digital surface models, and RGB and TIR orthomosaics. These images have significantly lower image registration errors compared to traditional methods which could aid in the detection of moving wildlife.

6. Using TIR Images to Create 3D Models Using Structure from Motion Processing

Structure from Motion (SfM) is a photogrammetric process that enables the automated image-to-image registration to create a 3D model by identifying points from a series of overlapping images taken from different vantage points and relating them spatially to one another to create a high-quality 3D image without needing to know camera location. The camera position and scene geometry are solved automatically during the process of matching features in the image sets. The identification of feature or ‘key points’ are automatically generated regardless of scale, location, and to some extent lighting in each individual image. The number of keypoints determined within an image is dependent on the image resolution and texture of the image. Images that have greater surface variability yield a higher number of keypoints since they have more identifiable features that can be used within the model. From the identification of these keypoints images locations in relation to one another can be created and the camera location calculated from the resulting data set. Once the initial scene has been created, it can then be projected into a real-world coordinate system by using ground control points (GCPs) with known coordinates. Most SfM applications have been done using RGB imagery. Thermal imagery has proven to be challenging to work (Yang and Lee, 2019) with within this method because of the inherent lack of texture within an image which makes it difficult to identify keypoints and reduces the overall definition of the point cloud. Truong et al., 2017 sought to overcome these limitations by fusing data from RGB and thermal cameras taken simultaneously. In their work they created RGB and thermal point clouds independently through SfM. Once the two clouds were generated, they filtered the thermal image to reduce noisy points arising from inaccurate matches between features in the thermal images. The next step was point cloud registration where they normalized the data and did a rigid body transformation to create a coarse registration, after this coarse registration a local registration is conducted using the *Sparse Iterative Closest Point* (Bouaziz et al., 2013). Using this method, they were able to register RGB and thermal point clouds generated by SfM and proved that this method can be used to increase the number of features detected in an image. They do also state that one of the limitations of this method is there will be noise introduced into the 3D reconstruction. Clarkson et al. (2017) conducted an experiment the used infrared imagery directly and had a similar experience with the number of points within the thermal dense cloud being less than optimal due to the limited complexity of the image (Thermal had 137, 064 points compared to the low-res RGB with 226,364 points). Their results were that while RGB point clouds yielded the highest accuracy overall thermal images may outperform RGB images on flat or homogeneous surfaces that have little visible texture but may exhibit a thermal gradient.

Chapter 3

Methods and Results

1. Overview

In the course of this study five aerial surveys and one ground-based survey were conducted to test the capacity of UAV-TIR imaging systems to detect thermal targets in a variety of scenarios. Of the five aerial surveys, one of the flights was conducted at over a model airfield with no tree obstruction using people as target objects, three were conducted in a grass field in the areas surrounding Carinthia University of Applied Sciences (CUAS) using people as target objects and the final flight was conducted at Abenteuer Affenberg which is a lightly forested area with a canopy height of approximately 30 m with Japanese Macaques (*Macaca fuscata*) being the primary thermal target. The initial testing was conducted to provide a sense of the cameras limitations and to work to optimize the flight procedure before flying over the monkeys to maximize our likelihood of collecting quality data and limit potential stress on the animals. One of the goals of this research was to test the applicability of RSI in moving animal detection however the systems available to us at the time of testing were unable to conduct the GPS image triggering to provide the nessceary accuracy to achieve ideal RSI imagery. To account for this, we flew the UAVs in as a consistent pattern as possible and visually inspected the sequential images to detect images pairs.

2. Site Testing

2.1 MFG Feistritz Gail

The preliminary testing was done at the MFG Feistritz Gail model airfield located in Carinthia, Austria located in the Gail Valley. The field was covered in closely cut grass with no major vegetation in the area. Figure 1 provides an orthomosaic image of the field as well as a ground level view of the test site. The flights were conducted on June 6th, 2019 between 09:23 and 09:39. The morning was uncharacteristically warm with a temperature of 25 °C at the start of testing which increased over the course of the study. A Leica Aibot Hexacopter was manually flown at an altitude of 40m and was equipped with a FLIR Duo R camera capable of capturing both RGB and thermal imagery simultaneously. One of the features of this camera is its ability to merge the two images into a Radiometric JPEG which superimposes the thermal data over the higher resolution RGB imagery. Infrared video was also captured during this testing. Seven GCPs were placed around the field to designate the study area and their GPS coordinates were collected. The targets of this study were ten people, with eight ice packs and three heat packs. The ice and the heat packs were placed around the study area the temperature range for the sensor. The human subjects were equipped with GPS trackers to log their movements and to

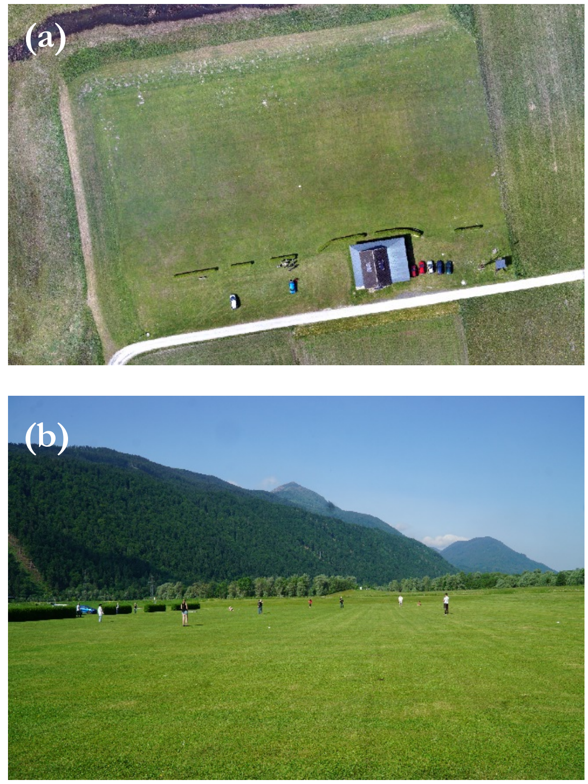

Figure 1. (a) An Orthomosaic image of the MFG Feistritz Gail field. (b) Image of the test site at ground level.

provide accurate locations for detection comparison. The testing was conducted in a series of four flights with different target movement patters. The first flight was conducted with no targets in the study area to give a base image. Then the targets were introduced and instructed to remain stationary for the duration of the flight. For the next flight targets were instructed to move randomly but slowly though the study area while being in constant movement. The images collected from these three tests were Radiometric JPEG imagery format. For the final flight, infrared video was collected, and the targets were instructed to move to a central location and then disperse. Unfortunately, due to the high temperature in the morning the thermal sensor was unable to detect any of the targets with any degree of consistency. It is interesting to note in some instances where the camera was unable to detect the target directly the shadow cast by the person cooled the area enough to create a contrast that is detectable by the thermal camera. Figure 2 is an example of the images acquired during this flight. The ice and heat packs were not detected by the sensor at that elevation and environmental temperature.

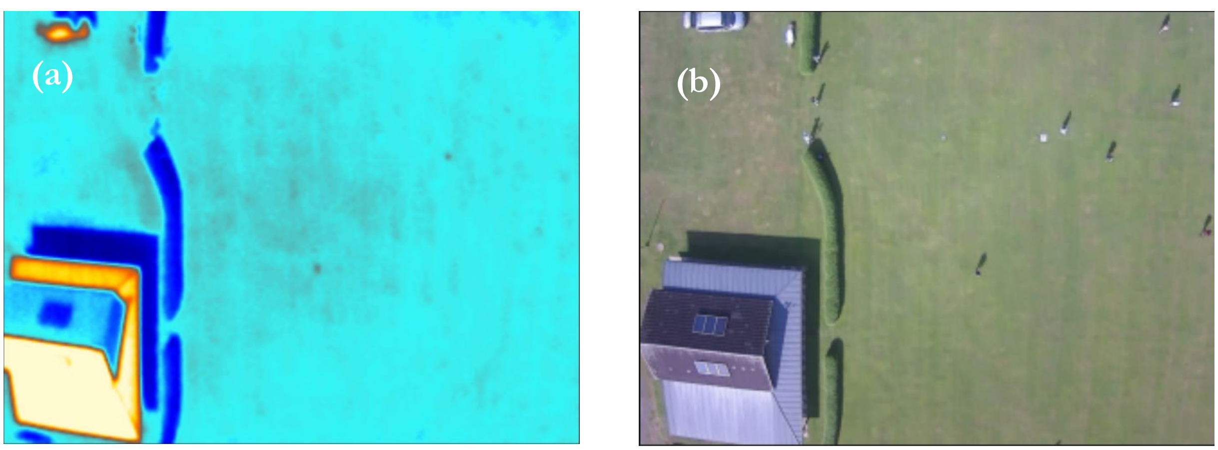

Figure 2. (a) Radiometric JPEG image captured by the infrared camera showing the hot spots on the image which are the roof of the building and the car but missing the human targets that are visible in the (b) RGB image.

2.2 Testing in the area of CUAS

Four tests were conducted in the area surrounding CUAS. The primary research objectives of these test sites were to determine the optimal flight conditions (time of day, atmospheric temperature etc.) and optimal flight parameters (flight altitude, image overlap) in more vegetative area but still without canopy cover. The tests were conducted in two fields. The first field was unmaintained tall grass with mixed vegetation. The second field was a lawn area of low-level grass that was well maintained.

2.2.1 Unmaintained Field adjacent to CUAS.

The second set of tests flights were conducted on June 14th, 2019 in a tall grass field adjacent to CUAS in Villach, Austria. Figure 3 provides an aerial view of the test site.

Figure 3. Aerial image of the unmaintained field with five targets.

The objective of this flight was to overcome some of the limitations of the previous test flight and to determine what is the optimal viewing height is given our sensor limitations. To try to limit environmental temperature interference these flights were conducted from 07:26 to 07:36 with an atmospheric temperature of 22 °C. Five people were used as targets for this survey with three standing in the tall grass and two people standing of the sidewalk adjacent to the field. The Lecia Aibot Hexacopter equipped with the FLIR Duo R was again used for this test. Three tests were conducted at this time. The first test was to determine what was the optimal height. To test this, the five people targets were told to remain stationary as the UAV was lowered at a constant rate starting at 60 m and then lowered to a height of 20 m. As the UAV was being lowered a video from the ground was taken to provide a noise reference at the different altitudes to determine at what height the UAV noise would be likely to cause stress on target wildlife. Another flight was flown using an automated flight plan over the targets to test the visibility of the targets in the tall grass area. One additional test was conducted in the parking lot beside the field where video was taken at an altitude of 40m and the targets were instructed to move around the study area and then congregate in the center. All the still images were taken in Radiometric JPEG format and the video in thermal infrared (see Figure 4). From this flight we were able to distinguish targets from the scene and determine the optimal altitude for flight was between 30 m to 50 m and that flying earlier in the day when it is cooler provides greater contrast is provides easier detection of targets. This image data set had limited post-processing due to the

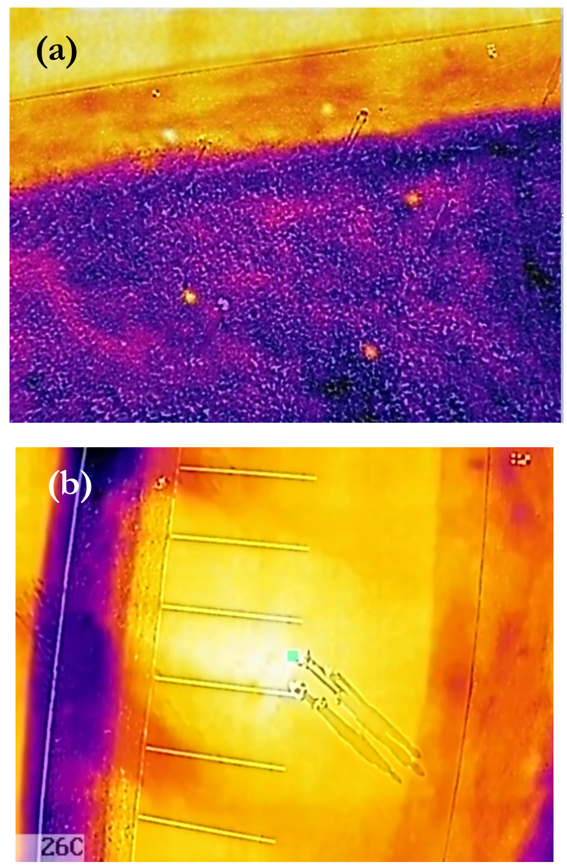

Figure 4. (a) Aerial image of the unmaintained field with five targets visible. (b) Image captured from the thermal video of people congregating in the center of the parking lot adjacent to the field.

specialization of the Radiometric JPEG which could only be read by specific software and had limited functionality within ArcMap and similar GIS and remote sensing software.

2.2.2 Maintained field in the adjacent to CUAS

A. Test 1

For the next round of testing we conducted a flight in a low grass field beside a walkway adjacent to CUAS campus using the Leica Aibot Hexacopter following a preplanned lawn mower flight pattern with an 80% overlap between images. The UAV was equipped with the FLIR Duo R with the image capture intervals set at one image per second. This area had moderate length grass and was surrounded by two larger trees. The test was conducted between 07:30 – 07:48 on July 3rd, 2019 with a surface air temperature of 19° C. GCPs were not used. For this test we did a series of three flights one each at 30 m, 40 m and 50 m. Three people (two adults and a child) were used as targets. One adult was stationary at the center of the study area, the other adult was instructed to move slowly within the area, and the child was instructed to move quickly around the area. The images collected were separate RGB JPEG and Thermal tiffs and then supplemented with RGB Video. An RGB orthomosaic was generated using Agisoft Metashape at each height (see Figure 5). The thermal images did not

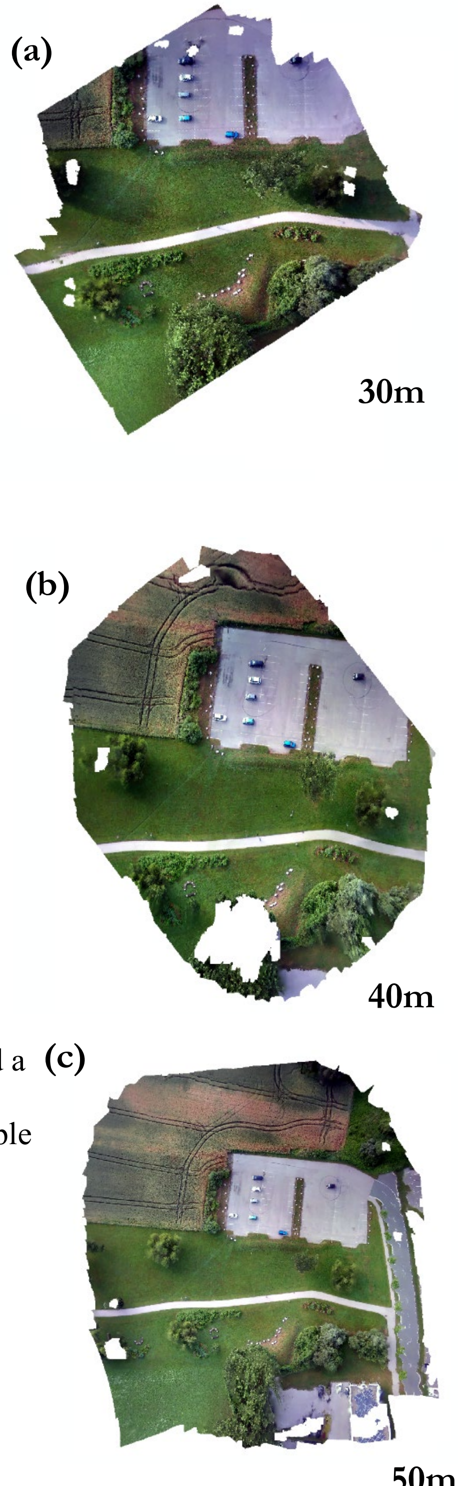

Figure 5. Orthomosaics generated at 30 m (a), 40 m (b), and 50 m (c).

have sufficient match points to generate an orthomosaic and were manually registered to the RGB Ortho image in ArcGIS using 1st order polynomial warping and a minimum 5 GCPs. Once these images were registered a binary image of each was created using radiometric thresholds from the thermal images. The thresholds were determined by selecting pixels from locations known to have targets taking the average value of those pixels and then broadening the threshold to +/- .5 standard deviation from that value to account for variability between images. The raster images were then converted to polygons and then center points were extracted to limit noise within the scene. The resulting images were then manually validated from the RGB images and coded to represent accuracy.

UAV Altitude	*Correctly identified Targets*	*Missed Targets*	*Falsely Detected Targets*	*Total Targets Identified*
30 m	19	1	3	23
40m	39	2	119	160
50 m	12	30	0	42

Table 1. The number of targets identified when using thermal thresholding by UAV height. 30m had the greatest accuracy with 82% of targets correctly identified. Both 40 m and 50 m performed poorly with 24% and 29% positive detection rates respectively

Table 1 displays the accuracy of the targets identified broken down into correctly identified targets, missed targets and falsely detected targets. Figure 6 shows the identified targets displayed over the orthomosaic image and is color coded to indicate the accuracy of each point. We concluded that the lowest flight elevation (30 m) was the most accurate at automatically detecting targets with 19 of 23 targets being correctly identified. At 40 m there was the greatest number of positively identified targets with 39 identified. However, this image was overclassified and resulted in 119 false positives but only had two missed targets. At 50 m the image was under classified. The while the image has zero instances of false detections, it had 12 instances of correctly identified targets, and 30 missed targets. There did not seem to be a difference in the detection percentage rates between movement patterns or size. The only difference is that both the moving targets appeared in significantly fewer frames which resulted in a lower level of detection.

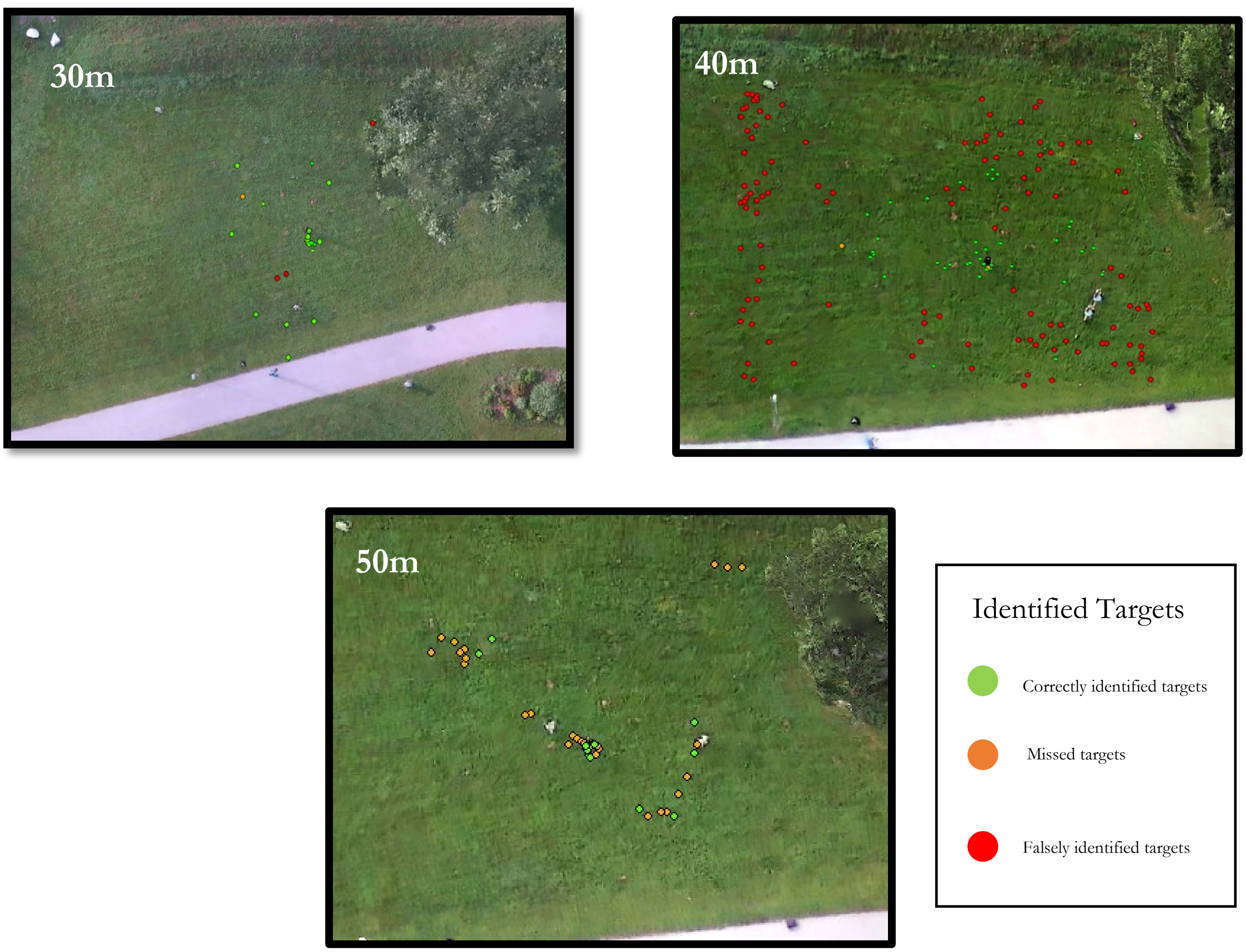

Figure 6. These images display the locations of identified targets from each image and then projected onto the ortho image. Red indicates that the target was a false positive, orange represents a missed target and green indicates a correctly identified target.

Given these results, it was determined that the optimal height would be at the 40 m mark but additional processing steps, such as accounting for target size, would need to be implemented to reduce the levels of false detection while maintaining positive detection rates.

B. Test 2

An additional test was conducted in a maintained field near CUAS with the goal of collecting GPS coordinates of the area through the placement and measurement of GCPs surrounding the area to aid in image to image registration. The Leica Aibot Hexacopter was flown at an altitude of 40 m and followed lawn mower flight pattern with an 80% overlap between images. The UAV was equipped with the FLIR Duo R with the image capture intervals set at one image per second and was flown on July 17th, 2019 between the hours of 09:33 to 09:39. At the time of flight, the surface air temperature was 25 °C. The targets were five people (three adults and two children). These tests results were inconclusive due to the heat which prevented target definition in comparison to the ground. Figure 7 shows the typical images resulting from this flight.

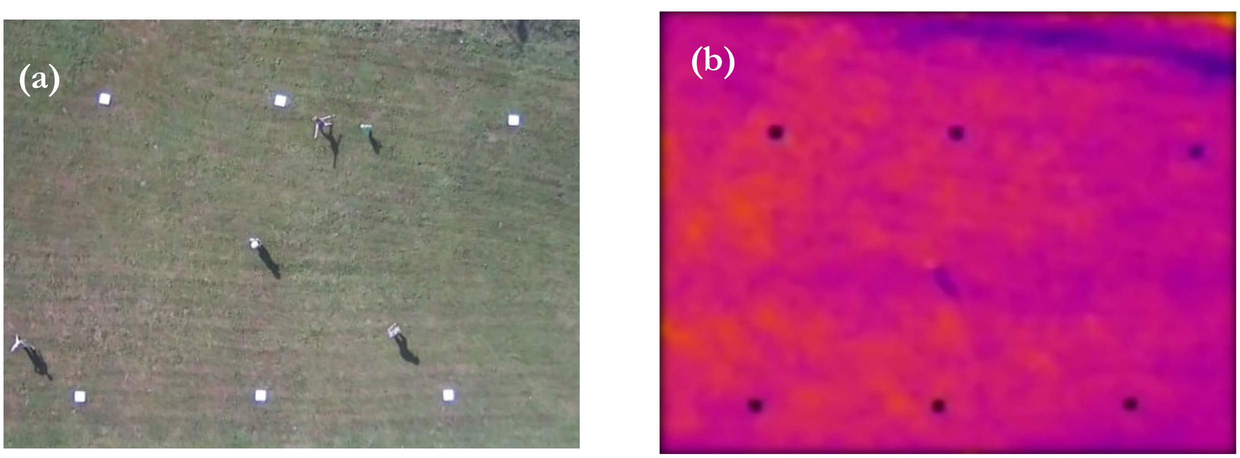

Figure 7. (a) RGB image from the flight on July 17th and (b) its corresponding IR image. The GCPs are clearly visible and the center target is also discernable but the targets in motion are not clearly visible.

GPS data were not collectable because of an interruption in Galileo satellite transmissions at the time of testing. An orthoimage mosaic was created but no further processing was conducted on the imagery.

C. Test 3

On July 31st, 2019 we conducted a test between 08:13 to 08:22 using five seated targets and six GCPs. The surface air temperature at this time was 19 °C. The Leica Aibot Hexacopter was flown at an altitude of 40 m and followed lawn mower flight pattern with an 80% overlap between images.

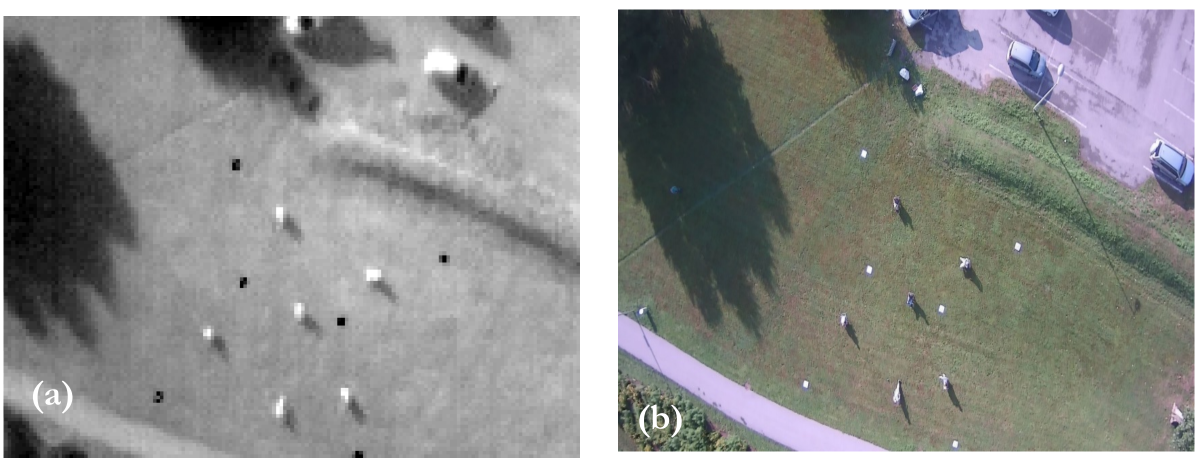

Figure 8. (a) IR image displays both the targets and GCPs in high contrast and provides similar levels of visual contrast as (b) the RGB image.

The UAV was equipped with the FLIR Duo R with the image capture intervals set at one image per second. This flight was conducted in two flight passes following the same flight pattern. For the first pass the targets were stationary for the duration of the flight and three of the five participants were instructed to change their positions between passes and then remain stationary.

This procedure yielded high contrast imagery (see Figure 8.) which is being used to test the RSI methodology and auto registration process. Research on the applicability of this process is still ongoing with no preliminary results available at this time.

2.3 Abenteuer Affenberg

Abenteuer Affenberg 4-hectare open-air enclosure housing 166 semi-free ranging Japanese Macaques in the Carinthia region of Austria and is run by the Austrian Research Center for Primatology. This is a minimally invasive research center that observes animal behavior and preforms hormone and gene analysis using non-invasive methods. This center is also a tourist attraction, allowing for guided tours among paths within the enclosure. A previous UAV study in this area was attempted a few years ago but had to be canceled due to an adverse reaction from the monkeys. We also had to factor in any possible interaction with a nearby aviary which hosts birds of prey which were also impacted by the previous flight. To prevent any undue stress on the animals, experts from both centers were on hand for the duration of the flight to help monitor the animals and alert us to any issues that might arise.

2. 3.1 Abenteuer Affenberg Ground Test

Before conducting a UAV based surveying ground-based testing was conducted to establish a baseline for the ability of the thermal sensors to detect the monkeys without canopy obstruction. Data was collected the morning of August 1st, 2019 between the 06:44 and 07:25 with a surface air temperature of 18 °C. Images were collected manually by walking though the exhibit using the thermal camera as you would a typical point and shoot camera. Approximate distances from target were monitored to help establish at what distance the monkeys would no longer be visible to the camera. From this we determined that the maximum reliable distance that we would be able to detect a monkey under these conditions would be approximately 30 m (see Figure 9)

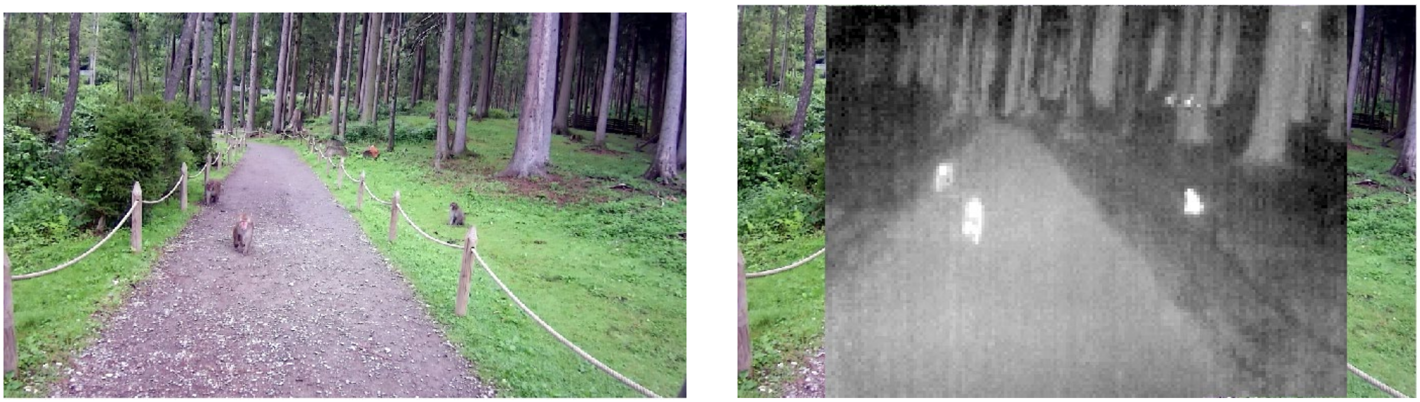

Figure 9. (a) RGB and (b) TIR images taken at ground level. The monkeys detected in the mid right section of the image were estimated to be at a distance of 30 m at the time the image was captured.

2.3.2 Abenteuer Affenberg UAV Test

For our final test we conducted an aerial survey of Abenteuer Affenberg on August 22nd, 2019 between 06:16 – 7:12. To limit the possible disturbance of the monkeys the flight was conducted using a DJI Mavic Pro equipped with a FLIR Duo sensor. The DJI Mavic Pro was used for this survey because it is considerably smaller and quieter than the Lecia Aibot Hexacopter and might be regarded as less of a threat. At the time of flight, the surface air temperature was 17 °C. The flights were conducted at 70 m to clear the tree canopy, which averaged 30 m, and to account for any animals in the tree cover that might be alarmed if the UAV was flown at a lower altitude. The testing was conducted in a series of three flights all along the same flight lines with 80% overlap between frames. The first image set was a series of still RGB and TIR images collected at one second intervals. This flight established a baseline for comparison with the next two flights. The second pass collected RGB and TIR videos. The final flight captured images in the same file format as the first flight with still RGB and TIR images being collected at one second time intervals. While these flights were being conducted, researchers within the park were monitoring the animals to ensure that they were not exhibiting any signs of stress to the UAV flying overhead. On the initial pass the monkeys did show an interest in the UAV by looking up as it flew overhead but quickly became desensitized to the noise and on subsequent flights paid no interest to the UAV. In the resulting images, we were able to distinguish human targets such as the piolet and the researchers inside the part but were unable to verify monkey sightings within the scene due to the limited camera resolution (see Figure 10). Hot spots were detected by the sensor but are unable to be confirmed by the matching RGB imagery.

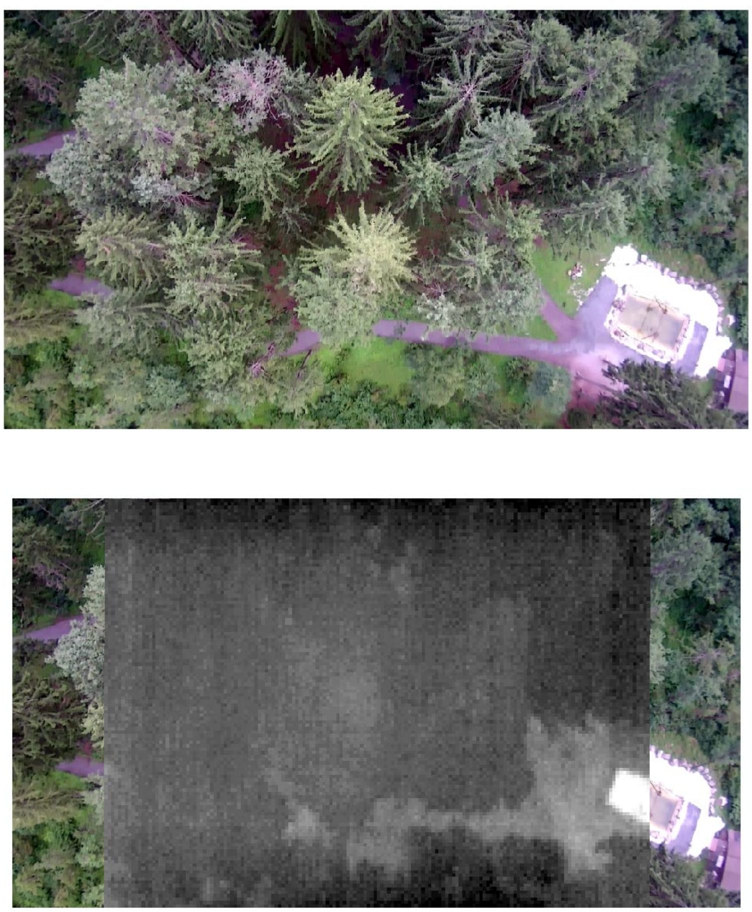

Figure 10. (a) RGB and (b) TIR images taken from a UAV at 70 m. There is some texture within the trees and the pool is clearly visible. There are potential hot spots within the but is unable to be confirmed.

Chapter 4

Discussion

1. Summary of Results

From the initial testing we determined that time of day was an important consideration and greatly impacted the results through atmospheric temperature differences as well as the solar heating of the ground and surrounding features. These results were then applied to the next phase of testing whose objective was to determine what is the maximum height where targets would be discernable. We flew in the early morning to maximize the contrast between the targets and the environment and proceeded to take images from descending heights starting at 60 m and going down to 20 m. From this we determined that the optimal range would be from 20 m to 40 m although there was enough contrast at 50 m to also make it a viable height for analysis. The next step in testing was to incorporate these findings and work to establish a work flow that would allow for target identification based on object thresholding. To achieve this, we conducted flights at 30 m, 40 m, and 50 m with the goal to identify three thermal targets in a low grass field. The results of this testing showed that at 30 m the target identification was predictably the most accurate having the both the lowest number of missed targets and misidentified targets and the highest number of accurate target identification. At 40 m the images have a high total number of targets correctly identified but also have several false positives. When flying at an altitude of 50 m the images have a drastic decrease in overall targets identified and an increase in missed targets which is to be expected as the UAV increases in altitude the differences between targets and background lose contrast. The next test flown at the same location was unfortunately unsuccessful do to the unexpected satellite outage as well as the increase in temperature which prevented thermal registration of targets.

The following phase of testing used stationary targets successfully captured high contrast images and had clear distinction between the background and the targets. The data from this experiment is still being processed to test its ability to be registered using RSI methodologies and auto-registration which would increase accuracy between images and enhance any change detection procedures we could potentially use moving forward to aid in target identification and classification. This was the last phase of testing before transitioning to the end test sight of Abenteuer Affenberg. Before conducting UAV based aerial testing over the area, ground testing was done to test the transferability of previously determined methods on smaller targets. Images were collected by walking through the exhibit with the FLIR Duo R camera and capturing images from the ground. From this we ascertained that monkeys up to 30 m away could be clearly picked up by the thermal camera, We then used this information to inform our the aerial surveying where we flew at an altitude 70 m (approximately 30 m above canopy) which was able to give us vague images of possible targets which were not able to be validated due to limited sensor resolution on both the TIR and RGB cameras.

2. Study limitations

The sensor resolution was a major obstacle within this study because it limited our maximum height and the coarser images limited the achievable accuracy when looking at automatic detection methods. Additionally, the inability to have automatic GPS registration of images reduced the accuracy of any change detection methods and limited the use of RSI methods for this study.

Chapter 5

Conclusion

This study tested the ability of a UAV-TIR imaging system to detect arboreal primates and what are the best conditions for detection. It was found that the thermal cameras ability to detect arboreal primates is greatly influenced by the time of day the testing as well as the sensors distance from the target. Flights flown earlier in the day at closer range were able to detect more thermal targets with the highest levels of differentiation. When looking at change analysis between frames it is easier to detect slower moving objects than faster moving objects because the targets will appear in more image frames. Ground based observations proved that using thermal cameras increased an observer's ability to detect monkeys in a forested area by creating a higher degree of contrast between the object and the surrounding environment. This testing also indicated that monkeys could be identified up to 30 m within the environment conditions of testing. During aerial testing, the monkeys did not exhibit an adverse reaction to the smaller UAV at 70 m. For the analysis of the images collected during this flight series, human targets were clearly discernable but signatures that could potentially be monkeys were faint and were unable to be confirmed using RGB imagery at the current image resolution. Further research needs to be done on the applicability of these methods when using a sensor with higher sensitivity. This would allow not only allow for more accurate manual image analysis but would also open the possibility of additional methods of analysis such as automated detection processes and 3D models generated from the thermal imagery. The accuracy of these assessment would also be increase with GPS registered images and the ability to have location-based triggering of image capture.

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