EXPLORING UAV TECHNOLOGY AND THERMAL IMAGERY TO AID IN TRACKING ANIMAL PRINTS IN THE WINTER

by

Brooke Davison

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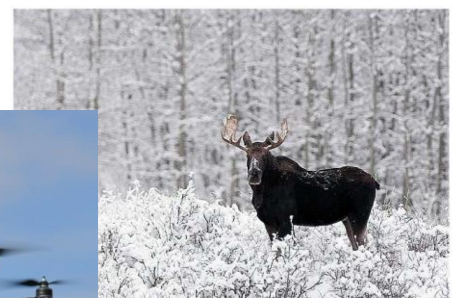

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EXPLORING UAV TECHNOLOGY AND THERMAL IMAGERY TO AID IN TRACKING ANIMAL PRINTS IN THE WINTER

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ABSTRACT

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Keywords: drone, pixel, survey, thermal

This study was done to test the ability for Unmanned Aerial System (UAV) equipped with thermal imagery cameras to detect thermal decay of footprints within the snow left by people, in hopes to apply thermal imagery and drones into wildlife surveying. The UAV DGI Inspire that was used and had a colour visual (RGB) ZENMUSE camera attached with an electronically stabilizing gimbal and the FLIR Vue Pro camera which is able to record and take images in thermal. The scope of the trial was for students to walk into a snow-covered McClusky airfield, fly multiple flights after and during the time that the tracks were being left and to analyze the images.

It was found that the pixel resolution and quality of the FLIR Vue Pro camera was not able to detect footprints left within the airfield. It is suggested to fly in a better suited area at colder temperatures and deeper snow, use a higher quality of camera, and fly at a lower altitude in future hopes of applying thermal imagery to detection of wildlife and their tracks.

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ACKNOWLEDGEMENTS

I would like to thank my advisors, Dr. Ulf Runnesson and Alex Bilyk. Their enthusiasm and encouragement throughout the project helped me gain applicable knowledge in a topic of my interest. Also, thank you to Ryan Wilke who had incredibly insightful input into the project and for piloting the flights out in the cold. The NRM faculty has provided me with a wealth of knowledge and opportunities that I look forward to carrying on with me in the future.

Another thank you to John Danahy for being part of the drone flight crew. Thank you to my fellow peers Summer Gidge, Julia Reale and Lawrence Tan for braving the cold with me and walking through snow to get the “perfect shot”. Also, thank you to Dave Morris who allowed me to borrow his Rogers internet stick to be able to send in my thesis to my supervisors while we were internet-less in Nakina.

INTRODUCTION

This study will focus on incorporating drone technology within the field of tracking mammals such as wolves and moose in the winter for population surveys and studies. The main hypothesis surrounds the idea that using Unmanned Ariel Systems accompanied with thermal cameras to detect thermal footprints left by animals within the snow will increase the accuracy of tracking animals for wildlife surveys, specifically wolves and moose. This will allow wildlife surveyors to save time, money, and also decrease safety risks by keeping surveyors on the ground and track thermal decay patterns left by animals.

This thesis was produced as a requirement for the completion of the Honours Bachelor's in Environmental Management. Lakehead University is the located within Thunder Bay which is on the northern shores of Lake Superior. Thunder Bay is relatively remote and surrounded by wilderness and many forms on wildlife. Thunder Bay is also home to many wildlife biologists and surveyors which use multiple methods to collect wildlife data. Wolves and moose are present within and surrounding Thunder Bay which gives wildlife surveyors opportunities to study these mammals.

Wolves and moose have an intimate predator prey relationship that is an interesting topic of study for many. By measuring and tracking wolves and moose, scientists can learn factors that affect each population and its interaction between each other. Drone technology is becoming a large importance to industry leaders for many topics of interest including research of these predator, prey relationships. Drones are not a way of replacing current technology, but a means of improving accuracy of surveys.

The traditional way that wolves and moose are tracked in the winter is by finding footprints in the snow and following them. Throughout the winter, aircrafts will go through aerial moose surveys. A fixed-wing aircraft will find and delineate the tracks, immediately followed by a helicopter crew. The helicopter allows for slower flight speed and hovering above an area if necessary. Although this technique has been used for many years, there needs to be changes implemented because of high cost, a lot of time, and dangerous elements introduced to wildlife surveyors when in flight. Much time is spent chasing tracks of animals that lead to dead ends, but by introducing new technology, this will hopefully absorb some of the negative factors that come with the current measuring techniques.

In addition to using drones within the field, the introduction of thermal imagery may change the way we track animals within the field forever. This trial of using thermal imagery to examine the temperature of wolf and moose tracks can only be tested in the winter because the snow will allow a clear temperature difference between the tracks and the surrounding snow. It has been observed that mammal tracks will leave behind a warmer footprint when stepped on and will then become colder due to lack of insulation within the track. It is also important to include factors that may change results including snow temperature, air temperature, and sunlight.

By using thermal imagery, we can tell if these tracks are fresh and worth following, depending on the thermal footprint left by the animal to see if it is still hot or possibly cold depending on when the track was left. In Figure 1 below, the image depicts animal tracks spotted within the snow taken from above from a helicopter in an attempt to track wolves and moose.

Figure 1. Photograph of animal tracks within the snow taken from a wildlife survey helicopter. http://www.earthrangers.com/wildwire/bbtw_updates/taking-to-the-skies-to-look-for-wolves/

A trial will be made to explore how mammal tracks leave thermal footprints within the snow that is able to be picked up using thermal cameras and tracked more efficiently. A trial study will be done using Lakehead students to walk through the snow-covered drone airfield outside of Thunder Bay to see if thermal footprints are visible. There will be two cameras attached to the drone during the flights which will be thermal and RGB. This data will be collected by attaching thermal cameras to the drones owned by Lakehead University.

In an earlier trial flown within Thunder Bay, promising results were found when flying above a local horse farm. The flight was done above Murillo Barn by a UAV above a group of horses to determine if their bodies and footprints within the snow would be visible. The flight was flown in both RGB and thermal. While examining the photos taken from the RGB flight afterward off of the memory card, the horse bodies were very visible in contrast to the snow. Also, there were visible tracks within the snow that seemed to be a high-traffic area for the horses within the snow. Figure 2 presents an above photo of the horses taken from the RGB camera.

Figure 2. Above RGB image taken of horses at the Murillo Barn.

The thermal imagery taken from the UAV flight above the Murillo Barn were also promising since the bodies of horses were a visible contrast against the snow. The thermal imagery that was flown was set to have warmer temperatures as white and colder temperatures of black. Within Figure 3 below, the warm body of a horse has a visibly white contrast from its body heat compared to the darker and colder snow. By flying multiple UAV flights above tracks left in the snow by student at the airfield in both RGB and thermal imagery, there will be visible and clear warmer and colder tracks left. Also, the bodies of the students will be captured and show as white bodied figures within the thermal images.

Figure 3. Above thermal image taken of a horse and tracks at the Murillo Barn.

There are also darker tracks seemingly made by the horses that show as darker trails within the photo. This is caused by the lack of insulation within the stomped down areas of the snow that causes the footprints made by the horses to be warm, then become colder before reverting back to ambient snow temperatures. The horse body would assumable mimic the body temperature and tracks of a moose within a forest during an aerial wildlife survey.

Since the warm bodies of the horses are visible within the Murillo Barn, the thermal flights within the McClusky trials should be the same. By flying multiple UAV flights above tracks left in the snow by student at the airfield in both RGB and thermal imagery, there will be visible and clear warmer and colder tracks left. Also, the bodies of the students will be captured and show as white bodied figures within the thermal images.

LITERATURE REVIEW

WOLVES AND MOOSE, PREDATOR VERSUS PREY

There have been many investigate studies that have observed moose and wolf predator/prey relationships. The effect of wolf (*Canis lupis*) predation on moose (*Alces alces*) remains a question of substantial theoretical and applied interest (Messier 1985). Many studies create hypotheses based around the impact that wolves have on moose populations and many have found that the limiting factor of moose is usually wolf predation, especially throughout winter months (Messier and Crete 1985). When comparing wolf density, which has been linked to nutritional status, there is a significant change when studying two separate areas with different moose densities. Low moose density in certain areas have results in a wolf density 40% lower than highly populated moose areas. The lower populated areas had wolves suffering from malnutrition and intraspecific combat. Also, with lower moose density, this results in lower success in wolf reproduction (Messier 1984).

Since apex predators have a large influence on the structure and function of top-down ecosystems, their responses to climate may shape responses at lower trophic levels. In response to increases in in winter snow related to the North Atlantic Oscillation, wolves hunted in larger packs and, consequently, tripled the number of moose killed per day compared to less snowy years when they hunted in smaller packs in Isle Royal. This shows the ecological consequences of predator behavioural response to global climatic variation using 40 years of data (Post et al 1999).

A study within Pukaskwa National Park, which is on the north shore of Lake Superior in central Ontario and lies in the Canadian Shield and the boreal forest was done to analyze different factors that affect moose population including wolf predation. Wolves were killing moose in the winter because there was no alternative large ungulate prey except a small herd of 25 caribou. There was an average of 2 fresh moose killed by wolves per annual survey, and each year the kills were taken by different packs. That means that 9 packs would kill 56 moose throughout the winter. Wolves took more animals each year than the number of calves still alive in February. At these rates, the moose population would have been reduced to 400 animals by 1979, with the estimated population at that time being 387 (Bergerud et al., 1983).

Another study was done in southwestern Quebec to test whether moose were regulated by wolf predation. Predation rates have been proved to be density-dependant by looking at moose densities and the fact that feeding observations indicated a greater use of alternative food resources by wolves at lower moose densities (Messier and Crete 1985).

MOOSE AERIAL SURVEYS

Throughout the winter, there are surveys of moose taken from aircrafts. A fixed-wing aircraft will find and delineate the tracks, immediately followed by a helicopter crew. The crew will then make an estimation of counts of animals depending on track networks (Crete et al 1983).

There have been a lot of development in wildlife surveys and population assessments in the past century. The three-major population estimate tools have been mark-recapture, distance sampling, and harvest models (Buckland et al., 2000). The direct method that is popular is capture-mark recapture experiments, where animals are captured, marked, released, and recaptured many times by repeated sampling. Although the catch the animals, they must be found first (Pradel 1996). These present methods of spotlight counts, mark to recapture, and current aerial surveys may affect the animal's behaviour patterns, therefore creating viewer bias (Havens and Sharp 1998). Managers will become increasingly dependent on high-tech systems for automated data recording, integrated with software to extract and model relevant data (Buckland et al., 2000). Introduction of drones into survey methods will provide a method for obtaining wildlife surveys with little risk of causing behavioural changes within the animal or sampling bias (Havens and Sharp 1998).

To study wildlife populations, indirect methods include scat collection in the summer, and tracks in the winter. A lot of the indirect methods of sampling are also done by aerial surveys but most counts of animals are an underestimate of the true total, because some animals are not seen during the census. This is especially true of an aerial census. There is a method that is presented for estimating the number of animals in an area from several counts, and then getting the mean from each of those estimates. This creates a source of bias and an inaccurate estimate from direct counting. For example, Todd Goddard set up an experiment to count black rhinoceros in the Olduvai Gorge, Tanzaia. There were a known amount of 69 rhinoceros' and then presented the results from 18 aerial consensus. Goddard gave 18 totals, the highest of which represented 50 percent of the true total. There was also considerable variability between the consensus that included weather, air speed, number of observers, and time spent counting (Caughley and Goddard 1972). All of these factors cost a lot of time and money and this shows that there is a large room for improvement. Drone technology has been booming and becoming increasingly popular over the last few years. There is an estimation by Teal, an aviation consulting firm that there will be about two million consumer drones, or unmanned aerial vehicles that will be sold worldwide in 2016 alone.

In addition to the large amount of time and cost that goes into organizing and undergoing fixed-wing and helicopter wildlife surveys, it is also extremely dangerous for wildlife biologists and surveyors. Ninety-one-job-related deaths were documented from 1937 to 2000 by the U.S. Wildlife Service, which listed aviation accidents as the number one cause of death (Sasse 2003). Thirty-nine aviation accidents of both aircraft and helicopters accounted for 66% of deaths, with aerodynamic stalls and power-line collisions being the most common cause of accidents while in flight. In all, there was 31 airplane and 7 helicopter accidents with most of the fatal flights flown for the purpose of wildlife or wildlife-habitat observation (50%) and radio telemetry (26%). These crashes are so common because of the frequent turns made to return to particular sites which cause stalls. The flights are low-altitude and low-speeds to enhance the ability of crew members to observe animals of locate radio tagged individuals but decrease the amount of area that is needed to recover from stalls, which inadvertently lead to many crashes (Sasse 2003). These safety threats, in terms of aviation surveys should be taken into consideration and plan for future safer procedures such as the use of drones. Drones are completely ground-operated and would keep wildlife biologists and surveyors safely on the ground

APPLICATION OF UAVS AND THERMAL IMAGERY IN WILDLIFE SURVEYS

Drones have been used by the military for several years, but civilian drones are catching up. Drones, also known as unmanned aerial vehicles (UAV's), are more advanced versions of model airplanes. They can come in airplane and helicopter varieties with spinning rotors. They can be piloted from the ground by a human with a radio controller or can have autonomous flights with programmed coordinates (Wingfield 2016). There has been great interest by Canada's public and private sectors in exploiting the advantages of UAV's. UAV's can operate in diverse environments and high-risk roles that can be that can be operated in environments unsafe for humans to be in or environments previously unmeasurable (Cavoukian 2012). Most UAV's are (or can be) equipped with camera technologies that can record and transmit photo images to a ground control stations. It is also possible to equip UAV's with sensors such as forward-looking infrared (or other thermal imaging) cameras that can detect infrared radiation, emitted from a heat source and create the "picture" assembled for the video output (Cavoukian 2012).

With mounting concern for more active management of wildlife in urban areas and parks, there is a need to obtain accurate information on wildlife populations. Aerial surveys for population census or estimation of wild animals are difficult. Aerial surveys are valuable tools for wildlife research and management. The use of small, unmanned aerial vehicles may offer promise for addressing these problems and become a useful tool for many wildlife applications such as collecting low-altitude aerial imagery. For

UAV's to be a useful management or research tools, they should be durable modular, electric powered, launch able and recoverable in rugged terrain, autonomously controllable, operable with minimal training, and collect georeferenced imagery (Jones et al 2006). Modern thermal-infrared (IR) scanning equipment has gained widespread attention of wildlife managers and trial use of the new technology is underway. Through computer analysis, IR thermography may become a useful wildlife population survey tool. It is also recommended that scanning should be limited to times that provide the highest thermal contrast and lowest thermal loading. This is best with a snowy background because of the high thermal contrast, but rainy days do not. Conditions where water accumulates on background snow should be avoided (Garner et al 1995).

Thermal imagery is just beginning to be considered and taken seriously in the context of wildlife surveying. Thermal signatures left by animals are able to be picked up using thermal cameras. A study in southwest Florida in 1998 conducted a survey of deer on video tape during flights. The thermal video and imagery counted 42% more deer when compared with standard RGB visual aerial survey methods (Havens and Sharp 1998).

MATERIALS AND METHODS

The area of study for this thesis were done in the McClusky Airfield. The McClusky Airfield is a space rented by Lakehead University that is able to be used for UAV flights. The airfield is located outside of Thunder Bay in the municipality of Oliver Paipoonge. The airfield is intersected near ON Highway 130 and McClusky Drive. The test flights for this thesis were undergone on March 15, 2017. This location has the proper area needed with an array of different terrain surrounding. There are trees around the area and it is large enough to hold the trial runs in. figure 4 is an above photo taken from Google Earth showing the McClusky Airfield in which the drone trials were done.

Figure 4. Aerial photograph of the McClusky airfield.

EQUIPMENT

The equipment that was used consisted of a DJI Inspire drone with rechargeable and changeable battery packs. The DJI Inspire drone comes equipped with the ZENMUSE X3 camera. The ZENMUSE X3 camera collects colour visual imagery and is electronically stabilized to the drone's movements. The additional camera attached to the DJI Inspire is the FLIR Vue Pro which collects thermal imagery and is attached by its own fixed-mount gimbal.

The DJI Inspire drone has a fully integrated intelligent battery powered system which virtually manages itself. While in flight, the DJI Inspire shows the remaining battery power and estimated time that the drone will return to starting point which allows the user of when to fly the drone back. There is also a failsafe backup for the Inspire drone despite all of its settings which puts the drone on autopilot when needed for situations such as low battery and connection to return back to the user (DJI 2017).

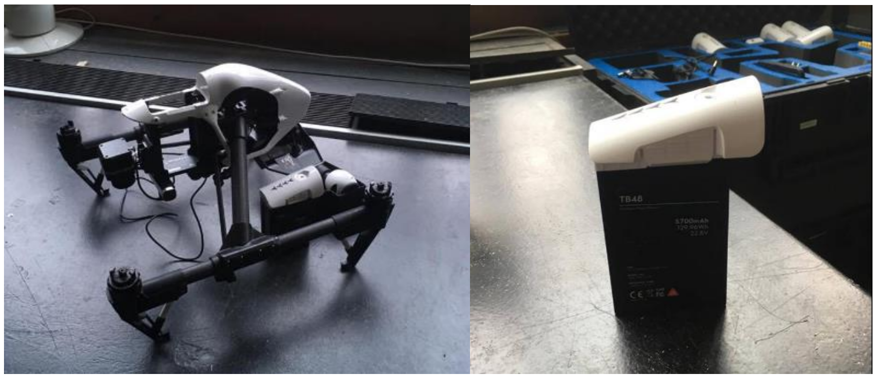

Figure 5. DJI Inspire drone and removeable rechargable battery.

The ZENMUSE X3 camera comes with the DJI Inspire 1 and is attached with an advanced, 3-axis, electronically stabilizing camera. The ZENMUSE camera has the ability to capture 4K videos and record at 4096 x 1080 (25 frames per second) or 1920 x 1080 (60 frames per second), has a 360 degree range, and takes 12MP photographs. The rectilinear curved lens design eliminated distorition and opens up to wide angle shots without a fish-eye look. The advaced gimbal that attatches the ZENMUSE X3 camera to the DJI Inspire drone constantly draws on data fed by the intellegent flight controller. This means that in changes in angular velocity, momentum and initial force is constantly being corrected every millisecond which keeps the camera perfectly level no matter on the flight (DJI 2017).

Figure 6. ZENMUSE X3 and gimbal.

The Flir Vue Pro camera costs approximately $1,999 and comes seperately and is attached directly to the DJI Inspire without a gimbal. The Vue Pro recores 8-bit digitial video and 14-bit still imagery to a removable micro-SD card. The Vue Pro is controlled by a built in Bluetooth module to mae it easily configurable with the users phone or tablet before take off. Within the settings of the Vue Pro, the user can change colour paletts, set image optimization features, configure PWM inputs, and start recording simply through the Bluetooth connection (FLIR 2017).

Figure 7. Flir Vue Pro camera.

FLIGHT PROCEDURE

The DJI Inspire was pre-programmed on Alex Bilyk's phone using the FLIR UAS app which can be downloaded on most phones and tablets. This application has many settings that can be applied to the drone's flight pattern including video recording and live-video streaming of the drones camera or still-captured images. The application also organizes that data setup such as file size, file type, and can set the colour palette. The flight area was input into the app and relayed to the DJI Inspire through Bluetooth connection. There were five flights total in total during the trial at McClusky Airfield on March 15, 2017. The pilot in command was Ryan Wilke, and the rest of the flight crew was John Danahy and Alex Bilyk. Each of the flights were at flown at 90m with an overlap of 90-90 to ensure that all areas traced were captured by the drone's cameras. Wind gusts during each flight varied between 10 and 11 kilometres per hour. A safety briefing between the crew was done at 14:00 and a preflight occurred at 14:05. The first flight was from 14:10-14:17 which recorded thermal video at 90m that acted as a control for the area. The second flight was taken after Ryan and John walked the area at 14:27-14:25 with thermal images taken at 90m. Flights three and four also took thermal images in an attempt the capture tracks left by Ryan and John. The third flight took place from 14:27-14:35 and the fourth flight was from 14:37-14:48. After the initial four flights were taken, myself and my fellow peers Summer Gidge, Julia Reale, and Lawrence Tan randomly walked the McClusky field while there were thermal images and video recording of the area as we walked throughout the field in an attempt to record the freshness of the tracks and our body heat.

Since the flight information from the FLIR Vue Pro is automatically saved onto an SD card, the photos were downloaded via USB. Alex Bilyk then uploaded the files in gif. format and was shared to myself via google drive. I converted photos of interest to pdf. and then began to analyze the images collected from the trial.

RESULTS

There were 400 thermal images from the five flights taken at the McClusky Airfield in total. RGB photos of the flights were also captured throughout the flights. The photographs taken varied in relevance and clarity depending on the camera that the images were taken from. The RGB images taken from the ZENMUSE X3 camera were much clearer and usable compared the thermal images taken by the FLIR Vue Pro camera. The below figure is a comparison of the RGB and thermal images taken of the airfield.

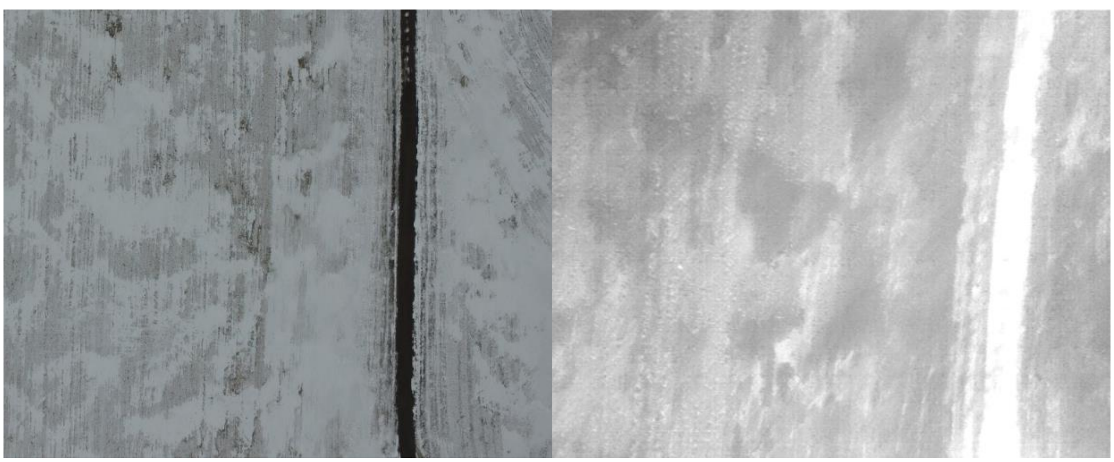

Figure 8. Comparison of RGB (left) and thermal (right) photos of McClusky Drive.

The side-by-side images above in Figure 4 depict a visible difference in clarity of the images taken throughout the flight. The road is visible in each image. Since the road is whiter in comparison to the surrounding area, it represents warmer temperature to the snow. The swaths of the lawn mower were somewhat visible within the thermal photos, while the RGB photos had clear visualization of the lawn mowers path on the field.

Also, since the photos were taken in late March, there was not a thick layer of snow which allowed some vegetation was able to penetrate and show through the snow which was visible in each of the cameras images.

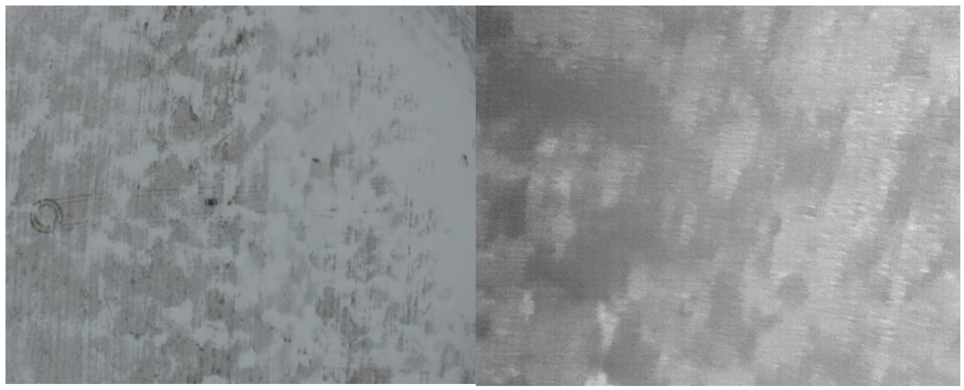

Figure 9. Above field photo for RGB (left) and thermal (right).

There are also noticeable tire tracks within the RGB image in Figure 6 which were actually visible in some thermal photos as well, showing up as hot spots within the images. Out of the 400 images taken throughout the five flights, only about 65% of the thermal images were usable in terms of clarity. Below are some examples of unclear photos taken by the thermal camera.

Figure 10. Blurry image taken by the Flir Vue Pro thermal camera.

Figure 11. High reflectance image taken by the Flir Vue Pro thermal camera.

Although some images were not usable for the trial analyses, interestingly there were clear heat spots on some trees that sides were facing the sun. The sides of these warmer trees showed as white in the images and showed promising results from the thermal camera in terms of the camera picking up relative difference of thermal changes.

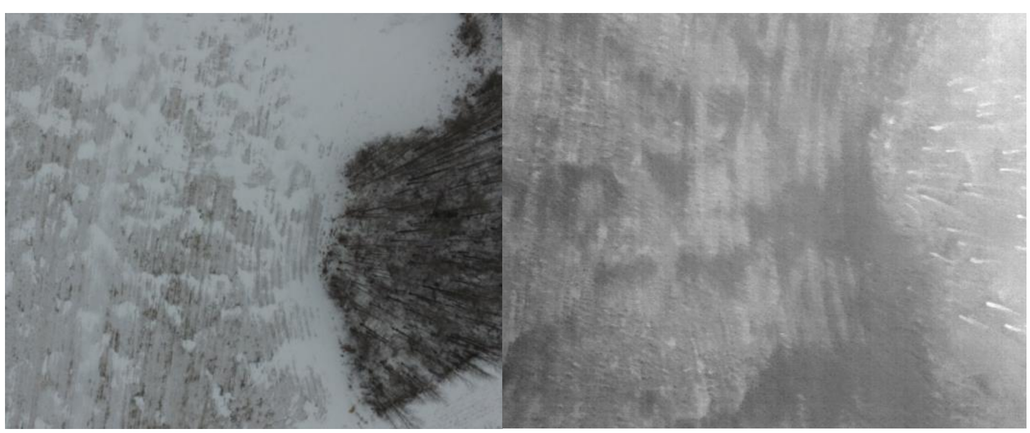

Figure 12. Comparison of tree stand between RGB camera (left) and thermal camera (right).

The two side-by-side images are actually quite clear from their results. The warmer sides of the trees show up well. Also, the snowy patches visible from the RGB photo would be cooler which accounts for the fact that the snowy patches show as darker on the gray scale in the thermal image. Although the relative temperature difference is somewhat visible in terms of the road and trees, no footprints or ground crew bodies were found in thermal images. Below depicts an above image of the study area with no visible or people.

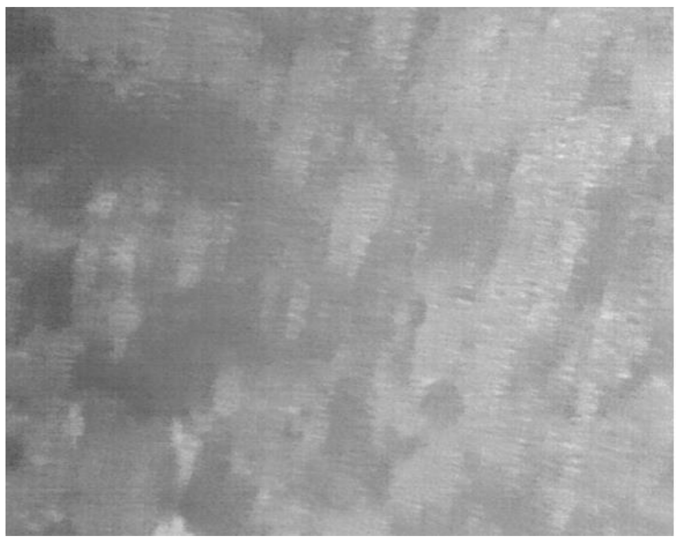

Figure 13. Above thermal image of the study area.

No footprints were found throughout many of the photos. Although, while the drone was still gaining altitude around the flight area, there are visible objects such as the table, and very clear detailed tracks of the side-by-sides tracks.

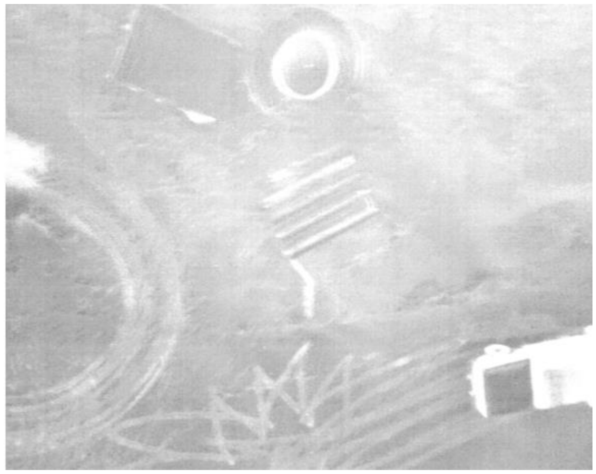

Figure 14. Detailed thermal image of flight area, taken as the drone was ascending.

Although there were no footprints visible from the 90m elevation, a foot and footprints were visible and stayed visible until the drone reached a certain elevation and then were no longer visible.

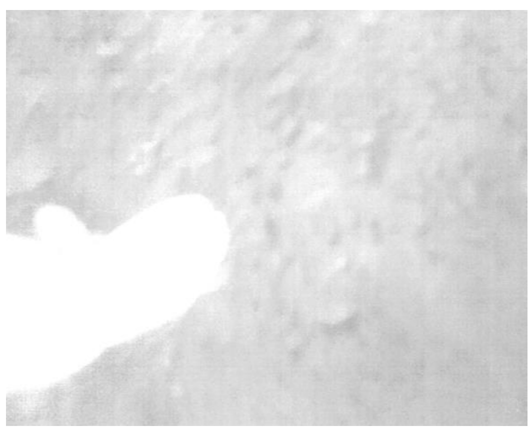

Figure 15. Thermal photo of a foot taken as drone was ascending.

The thermal image of the foot was very visible and showed the high temperature of the body temperature in contrast to the colder snow. From these ascending photographs, there were some thermal identification of footprints but only at low elevations.

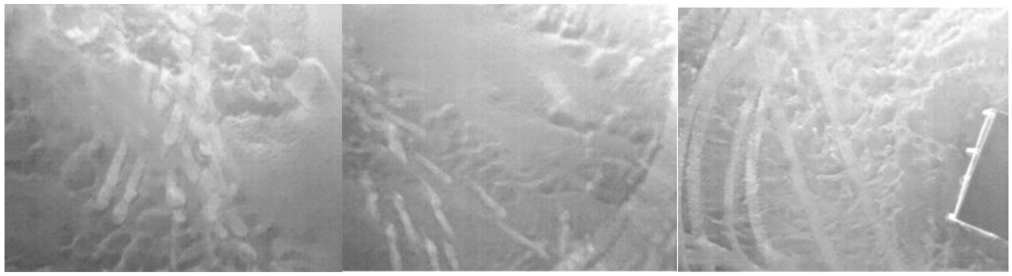

Figure 16. Footprints become less visible with thermal camera as drone ascends.

Unfortunately the trial was unsuccesfful in the sense that no footprints left by people or human bodies themselves were found in any of the imagery unless extremely close-up before the drone reached its set elevation of 90m.

DISCUSSION

REASONS THE TRIAL DID NOT WORK

The hypothesis is null and was not able to detect thermal footprints left by warm-bodied tracks within the snow. This does not necessarily mean that it will never work in another study or other conditions, it simply means that this specific trial and set up was not successful. There are many reasons as to why the trial at the McClusky airfield did not work. One of the first reasons is possibly the date at which the measurements were taken. The flight was not conducted until late March, therefore allowing vegetation exposure which may have interfered with the clarity of thermal difference between snow and warmer temperatures. The patchiness of the vegetation was quite clear but there was no clear sign of tracks throughout the area. As well as the vegetation patches being present throughout the images, the trail of the lawn mower was also visible, these trails should not have been visible which indications that there was not enough snow cover.

Also, the resolution the flight was being flown did not seem to be high enough to capture clear images. The comparison between the ZENMUSE X3 RGB camera and the

Flir Vue Pro was quite clear. Since the footprints were visible at a close range but lost visibility as the drone gained altitude, the pixel resolution was too low. As the Inspire drone gains altitude in metres, the pixel area in centimetres increases so there is more area covered per pixel which creates blurrier images. Ryan Wilke provided me with a table that he created by calculating the ground sampling distance.

The GSD can be calculated using this simple equation:

GSD=flight height/focal length x pixel size

By substituting in each changing altitude, the following table was created.

Table 1. Ground sampling distance of Flir Vue Pro and Inspire 1.

FLIR Vue Pro 640 GSD				Inspire 1 X3 FC350 GSD			
Altitude m	Pixel Area cm2	Pixel Area m2	Image Area m2	**Altitude m**	Pixel Area cm2	Pixel Area m2	Image Area m2
10	0.7943024	0.0000794	26.0277008	**10**	0.1805138	0.0000181	216.616512
20	3.1772096	0.0003177	104.1108033	**20**	0.7220550	0.0000722	866.466049
30	7.1487215	0.0007149	234.2493075	**30**	1.6246238	0.0001625	1949.548611
40	12.7088383	0.0012709	416.4432133	**40**	2.8882202	0.0002888	3465.864197
50	19.8575598	0.0019858	650.6925208	**50**	4.5128440	0.0004513	5415.412808
60	28.5948862	0.0028595	936.9972299	**60**	6.4984954	0.0006498	7798.194444
70	38.9208173	0.0038921	1275.3573407	**70**	8.8451743	0.0008845	10614.209104
80	50.8353532	0.0050835	1665.7728532	**80**	11.5528807	0.0011553	13863.456790
90	64.3384939	0.0064338	2108.2437673	**90**	14.6216146	0.0014622	17545.937500
100	79.4302394	0.0079430	2602.7700831	**100**	18.0513760	0.0018051	21661.651234
150	178.7180385	0.0178718	5856.2326870	**150**	40.6155961	0.0040616	48738.715277
200	317.7209574	0.0317721	10411.0803324	**200**	72.2055041	0.0072206	86646.604938
250	496.4389960	0.0496439	16267.3130194	**250**	112.8211002	0.0112821	135385.320216
300	714.8721542	0.0714872	23424.9307479	**300**	162.4623843	0.0162462	194954.861111
400	1270.8838296	0.1270884	41644.3213296	**400**	288.8220165	0.0288822	346586.419753

As the altitude increases, the pixel area increases which increases the image area in metres squared overall which makes for a less precise photo. Since foot size is relatively low, while the drone is at 90m, it would not be able to pick up small shifts shape temperatures at that size.

Although there was a lot of issues with pixel resolution, issues such as blurriness and flare was also an issue. This was caused by the FLIR Vue Pro being attached directly to the DJI Inspire. The ZENMUSE X3 had such clear photos because it was attached to the drone using an automatically electronically stabilizing gimbal. This allows the drone to change in direction, speed or tilt suddenly and the photos not be effected from being stabilized on a millisecond basis. Unfortunately, the FLIR Vue Pro thermal camera was simply directly attached to the drone. This means that whenever the drone would shift suddenly or change direction, the camera would also move suddenly which lead to motion blurring. In addition to blurry photos, there seemed to be a lot of glare and flare from the snow. Many pictures within the 400 inventory were mostly just white because of the sudden movements of the drone would only allow the camera to quickly pick up the snows cool thermal reflection. There were also gusts of wind throughout the five flights which would add complications from the drone attempting to correct itself from movement of the wind.

In addition to the patchiness from vegetation, the Flir Vue Pro only has relative scale in terms of temperature difference. This means that the camera is not able to measure specific temperature, but only show relative change in temperature throughout an area. This will lead to inaccurate representation of temperature change since areas can seem more dramatic or less dramatic, depending on the relevant temperatures surrounding an object. Although there are many reasons that this trial did not work, there are also many future suggestions for other studies to change their methods to improve their results.

SUGGESTIONS FOR FUTURE TRIALS

The first change to this trial would be time of year that the trial was conducted. March 25 was too late in the season to be able to obtain accurate ground thermal readings. The patchiness of the snow, lack of snow, and relatively warm temperatures lead to patchy areas that would make it difficult to spot tracks in any area. The trial should be conducted while the temperatures are at a constant of below negative five degrees. Also, there needs to be more snow on the ground, suggestion of at least 20 centimetres. This will aid in a more constant background to objects and will indicate a change in temperature much more clearly.

There are also better options for a thermal camera than a FLIR Vue Pro. The issue with the FLIR Vue Pro is the poor resolution which leads to unclear images and only being able to measure temperature in relative scale. With better resolution, photos would be clearer and would be easier to visualize outliers of the constant area. Throughout the thermal images, the side-by-side tracks were visible from the 90m altitude. This must be from the side-by-side tracks having a larger surface area for the drone to be able to pick up. Smaller sized footprints were only visible from about 30m up. Flying at lower altitudes would also be very helpful. Drones are able to cruise at low altitudes and have low impacts on behaviours of surrounding wildlife so the ability to fly low should be taken advantage of.

A radiometric temperature scale within the thermal camera would be a huge advantage. It would no longer classify temperatures of objects based on the relative temperatures of objevts around them, but would base temperatures of objects accurately. The FLIR Vue Pro R has the ability to radiometrically measure and has a better pixel resolution for only approximately $1000 more than the FLIR Vue Pro. This would increase image quality and clarity. Also, the fact that the FLIR Vue Pro was directly connected to the DJI Inspire had huge detrimental effects to the quality of images. By possibly attaching with an external and automtacically stabilizing gimbal, this would make a large different in motion blurriness.

CONCLUSION

Although no tracks or bodies were detected within the thermal imagery, this does not mean that future studies can't improve the techniques and materials that were used in this trial to have different results. Drones fly best in conditions that fixed-wing planes and helicopters also fly best in. Although the research and calibrations are not presently implemented, the future is promising for thermal technology and UAV's to become a routine measuring tool for wildlife. Drones are less expensive than planes and helicopters and also take less time, both in flight and planning. To plan for an airplane and helicopter to fly in a day, it takes a lot of planning and hoping for the perfect conditions on the day that the flight was planned for, whereas with drones, there is no planning needed and a wildlife surveyor could wait until the weather conditions are in favour to fly. Another advantage is that drones are user friendly and with some training, anyone can fly a drone whereas it takes many years to be able to fly a plane. It will allow an increased margin of freedom for wildlife surveyors to measure sample plots on their own time. In addition to the saving of time and money, the use of drones in replacement of aircrafts may also save lives. The ground is a much safer place than flying at low-altitudes in aircrafts for surveying. Drones are also able to fly and hover at lower altitudes to get better angles if needed. Also, after flying a drone, the video and images can be looked at post-flight for closer inspection in case of any missed animals or signs of animals. Thermal imagery will be able to detect wildlife much easier for future wildlife biologists and surveyors, there just needs to be more research and time into the development.

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