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HOTSPOT DETECTION IN HARVEST DEBRIS BURN SITES

INFRARED SENSING USING REMOTELY PILOTED AIRCRAFT SYSTEMS

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ABSTRACT:

FPInnovations collaborated with BC Timber Sales and Hummingbird Drones, a company with expertise in wildfire hotspot detection, to explore the use of a DJI Inspire 1 Pro remotely piloted aircraft system equipped with a thermal sensor as a hotspot detection tool.

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BACKGROUND

Infrared imaging technology has been used for over four decades in support of wildfire management operations across North America. This technology has been utilized in several different combinations of sensors and operational platforms to achieve a broad range of strategic and tactical fire intelligence objectives.

The ongoing evolution of remotely piloted aircraft systems (RPASs) with recent advances in micro-sensors and imaging software has provided another "tool in the toolbox" for wildfire managers and prescribed burn practitioners to enhance the delivery of infrared imaging services. Thermal imaging using manned aircraft and RPASs has been used extensively to locate hotspots within wildland fires and areas of burned harvest debris. Hotspot detection operations using RPAS thermal imaging technology is provided primarily by contract service providers.

INTRODUCTION

BC Timber Sales (BCTS) monitors burned harvest debris piles in the spring season to ensure these piles have self-extinguished overwinter. Ground-based visual/infrared inspections are time consuming while manned aircraft infrared scanning is relatively expensive. BCTS works with the BC Wildfire Service (BCWS) to conduct broadcast burns in harvested sites to reduce hazardous fuel loading and to prepare the site for reforestation. Complete extinguishment of these spring burns is also critical.

BCTS would like to explore opportunities to use its own DJI Inspire 1 Pro RPAS with a thermal sensor to conduct hotspot detection missions in areas of burned harvest debris (e.g., burned piles or broadcast burns) to ensure extinguishment of these burn sites and mitigate the potential for escaped fire. FPInnovations collaborated with BCTS personnel and Hummingbird Drones, a company with expertise in wildfire hotspot detection, to explore the capabilities of the technology.

OBJECTIVES

This research project deployed RPASs with infrared scanning sensors to search for hotspots in cutblocks following prescribed fires. FPInnovations’ objectives were as follows:

- Facilitate knowledge exchange of hotspot detection infrared scanning practices between BCTS and the subject matter expert, Hummingbird Drones
- Outline infrared scanning procedures and data analysis processes utilized by BCTS and Hummingbird Drones
- Identify knowledge and technology gaps between BCTS and Hummingbird Drones
- Identify solutions (technology upgrades or enhanced workflows) that could close these gaps

RESULTS

Overview

BCTS targeted two active prescribed burns in the Kootenay Lake Fire Zone as test sites to deploy two independent RPASs conducting infrared scanning missions. FPInnovations acquired the services of Hummingbird Drones to:

- Perform infrared scanning missions at these sites.
- Consult as a subject matter expert to assess and compare the current systems used by Hummingbird Drones and BCTS.
- Recommend solutions that can enhance delivery of an infrared scanning program with operational workflows that could be implemented by BCTS.

Comparison of hotspot detection systems

A remotely piloted aircraft system (RPAS) is defined as "a set of configurable elements consisting of a remotely piloted aircraft, its control station(s), the command and control links and any other system elements required during flight operation" (Government of Canada, 2018). Remotely piloted aircraft (RPA) means a navigable aircraft, other than a balloon, rocket or kite, that is operated by a pilot who is not on board. Other system elements essential to an infrared scanning operation include a thermal sensor and data interpretation tools. In order to compare the infrared scanning systems operated by BCTS and Hummingbird Drones, each component was identified (Table 1) to assess its capabilities, limitations, and how it impacts the overall performance of the system.

Table 1. Comparison of RPAS components and thermal imaging systems

	Hummingbird Drones	BC Timber Sales
Aircraft	**DJI Matrice 100**	**DJI Inspire 1 Pro**
Notable features	Enhanced GPS Dual battery compartments	Retractable legs and 360 degree rotation of camera mount enhance photo/video
Endurance	30 minutes	18 minutes[a]
Sensor	Zenmuse XT FLIR (6.5 and 12 mm)	Zenmuse XT FLIR (7.5 mm) f/1.4
	Both sensors are gimbal mounted	
User interface		
Tablet		iPad mini
Flight planning software	DJI Ground Station Pro	DJI Ground Station Pro
Data interpretation	Proprietary software	Visual/first-person view

[a] From DJI performance specifications as shown on the company's website (https://www.dji.com/ca/inspire-1/info).

The DJI Inspire 1 Pro (Figure 1) used by BCTS was designed for professional aerial photography and filmmaking with features such as retractable legs that do not obscure camera view and a gimbal-mounted camera with 360-degree rotation.

Figure 1. Components of the DJI Inspire 1 Pro RPAS including aircraft, sensor, remote controller, and tablet.

The DJI Matrice 100 (Figure 2) used by Hummingbird Drones has enhanced GPS capability and dual battery capacity. The longer endurance can contribute to a more efficient hotspot detection operation while the GPS system may result in more accurate location of hotspots.

Figure 2. The Matrice 100 packed in its hard case (left) and assembled (right) showing enhanced GPS antennae.

Thermal scanning on prescribed fires

Hooker Creek prescribed burn – May 8, 2019

The thermal scanning trial at Hooker Creek was conducted on a 29-ha site that had been burned by BC Wildfire Service in the first week of May. This site is approximately 70 km north of Creston, B.C. Upon arrival (19:30) at the upper boundary of the Hooker Creek prescribed burn site, Hummingbird Drones and BCTS conducted a visual survey of the prescribed area to identify obstacles in the site and plan a safe flight path. Because the site is on steep terrain (100%), a cross-slope flight path was chosen that would start at the top of the burn area and maintain a pre-determined height (approximately 300 ft.) above the height of the launch area for the entire scan. Maintaining this height would ensure that obstacles in the scan area (patches of trees) would be avoided.

The next task conducted in Hummingbird Drones' workflow was to fly the area with the Matrice 100 fitted with a standard RGB camera, and capture images to be used in building an orthomosaic map of the area. Terrain-following technology was not used; this technology was viewed as unnecessary for these missions and somewhat unreliable. Building an orthomosaic map is not always possible for all missions when a scanning team arrives on site after dark. The orthomosaic map is used as a base map in the infrared image analysis stage to align detected hotpsots with visual reference points. This results in greater accuracy in georeferencing identified hotspots. Flying over the site and capturing images for the orthomosaic map required about 10 minutes with two passes over the prescribed burn area.

After landing the RPA at the launch site, images on the SD memory card were screened to remove images of poor quality (out of focus or view obstructed by RPA legs). The orthomosaic of the prescribed burn area was produced on site using a commercially available software program in about 30 minutes.

The infrared scan was conducted at 21:30 and lasted about 15 minutes. The infrared scanning flight path required three passes. The SD memory card was removed from the RPA and images were analyzed on site using proprietary software developed by Hummingbird Drones. During the image analysis phase, each individual infrared image was viewed on the computer screen (Figure 3) which displayed the infrared image with a histogram indicating anomalies in heat signatures alongside the orthomosaic map.

The location that is geotagged with the infrared image is fine-tuned by referencing objects in the orthomosaic map such as nearby downed logs or trees to acquire a more accurate location of the hotspot. As an operational deliverable, within 30 minutes of the RPA landing, a hotspot map was produced showing the GPS locations of each hotspot and the hotspots on the orthomosaic map (Figure 4).

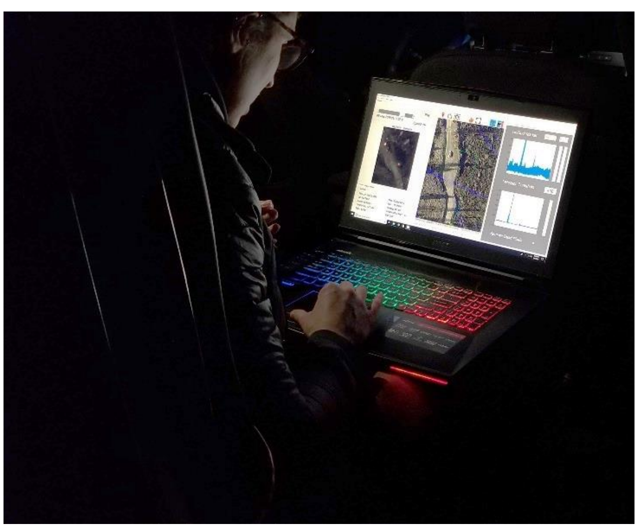

Figure 3. Image analysis process displays histogram of heat signature anomalies and hotspot location on infrared image and orthomosaic map.

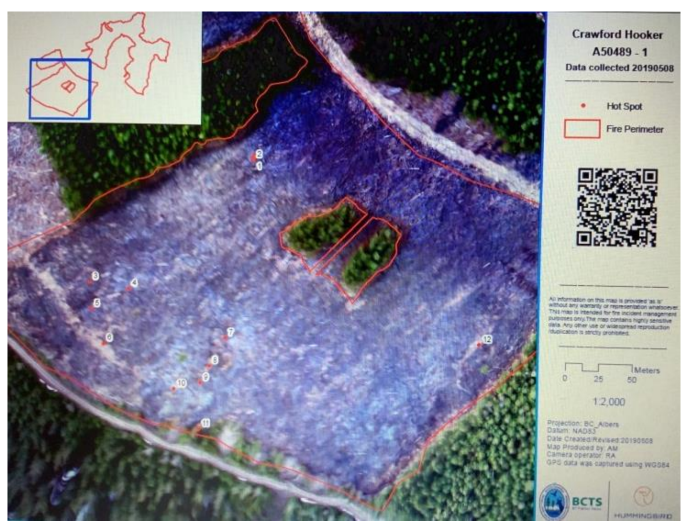

Figure 4. Hotspot map produced as the deliverable from infrared scanning mission.

The laptop requires significant battery power to perform the orthomosaic imaging and infrared image analysis. A portable generator was on site to power the laptop and charge the RPA batteries.

Goat River prescribed burn – May 9, 2019

The Goat River prescribed burn is part of a 27-ha harvested site approximately 25 km northeast of Creston, B.C. This block is on an 80% to 90% east-facing slope that had been burned by BC Wildfire Service fire crews on May 7. During the first flight (visual line of sight) to acquire images for an orthomosaic map, the flight path was recorded and saved for re-use during the infrared scanning flight. Unlike the initial flight at the Hooker Creek trial, the pilot followed the terrain more closely to maintain the same height above ground level throughout the entire flight. This process was introduced as another flight planning option to avoid obstacles on subsequent flights at night. When the saved flight path is flown, the RPA will follow the original flight path and maintain a more consistent height above ground throughout the flight.

The same infrared scanning and data interpretation processes were used at this site, with additional time for discussion of the workflows and opportunity to fly the BCTS Inspire 1 Pro on the site and capture infrared imagery. Several heat signatures were identified with the Inspire 1 but it was difficult to distinguish between positives and false positives (as viewed in the first-person view on the tablet screen).

During both scanning operations, the weather was warm and dry with minimal wind. These were optimum conditions for infrared scanning since rain or high humidity disperses an infrared radiation signal. With good vantage points on both missions, visual line of sight was maintained throughout the missions. For night flight missions, Canadian Aviation Regulations 901.39 (Government of Canada, 2020) states that an RPA must have position lights that are visible to the pilot and visual observer.

Debriefing and identifying technology gaps

In the debriefing of these infrared scanning trials, the team identified a key technology gap of image analysis and interpretation. The proprietary software developed and used by Hummingbird Drones was essential for expedient and accurate image analysis. This software interprets each individual image and identifies individual pixels that exhibit a heat signature above a set threshold.

Without this technology, users rely on visual image analysis to detect hotspots in the first-person view while flying an infrared scan. This method is commonly used by some infrared scan operators using a manned aircraft with an infrared camera operator scanning for hotspots and marking these points with a GPS unit. Alternatively, when a series of images is captured during an infrared scanning mission, users could analyze each individual image at a later time to identify hotspots.

The team proposed a potential solution that would entail capturing infrared images with a BCTS RPAS during a scanning mission and forwarding these images to a service provider to have the images analyzed with hotspots identified and geolocated. A single scanning mission could collect hundreds of images and large files would likely be transferred via a File Transfer Protocol (FTP) with the deliverables returned to BCTS by the same mechanism or by email. These deliverables could include an orthomosaic map, hotspot map, and a list of geolocated hotspots. FPInnovations and BCTS recognized this solution as one that could be explored by analyzing infrared images captured through simulated hotspot detection infrared scanning missions. As part of this exploration, the timeframes for transferring and processing images would be evaluated.

Simulated hotspot detection trials

To address this primary technology gap and explore the opportunity of having a service provider interpret infrared image data, FPInnovations conducted hotspot detection trials at the Canadian Boreal Community FireSmart (CBCFS) research area at Fort Providence, N.W.T. In July 2019, researchers set up an infrared test grid with simulated hotspots in a forested area and flew missions to acquire infrared images to be analyzed at a later time. The objective of these simulated hotspot detection trials was to collect images that could be analyzed by a thermal imaging interpretation process operated by an external service provider.

The simulated hotspots (Figure 5) were manufactured specifically for use at the Hinton infrared evaluation grid (Gibos and Ault, 2009) operated by Alberta Agriculture and Forestry to evaluate the performance of thermal imaging service providers in detecting hotspots.

Figure 5. Simulated hotspot used in detection trials.

These extra field trials also allowed FPInnovations to identify and perform tasks that are essential in creating workflows for pre-flight planning, site evaluation, flight execution, and data analysis. FPInnovations used a DJI Mavic 2 Enterprise Dual with a FLIR Lepton thermal microcamera to scan the trial area. DJI Pilot software was used to program a grid pattern flight path at an altitude of 80 m, side overlap of 80%, and front overlap of 80% (Figure 6). The overlap and height set in the flight planner dictate the number of images captured during the mission.

DJI Pilot allows the user to plan a mission in three different ways. For the CBCFS trials, this flight planning tool was used to draw the boundaries of the scan area as a polygon overlaid on a satellite map (Figure 6). This was possible because several land features were visible in the map overlay and the polygon could be set in relation to map features. This flight was planned on an Android phone using the DJI Pilot app. Other flight planning tools may be more efficient using a desktop software product.

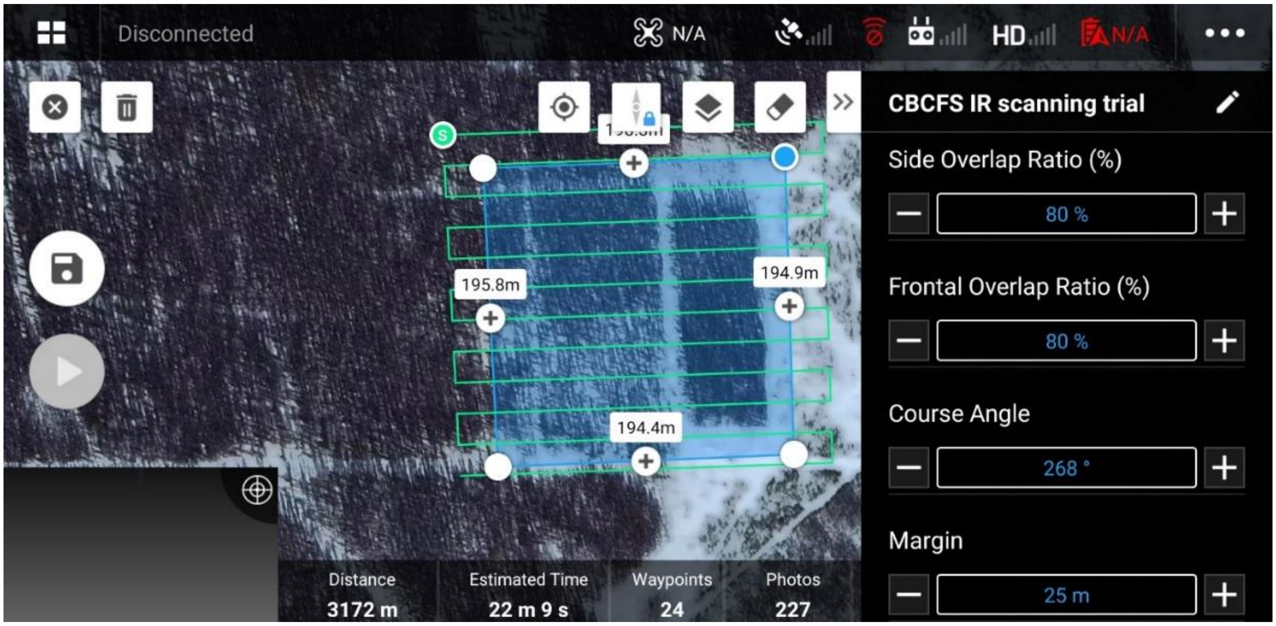

Figure 6. Image capture parameters and the flight path plotted with DJI Pilot for the 4-ha scan area.

Another option for setting the boundaries of a scan area is to download a .kml file to the flight planner. This will be a better option when a burn area has been pre-defined with a shapefile and this is the area of concern for an infrared scan.

A flight mission can also be planned by setting the waypoints of a route and marking these waypoints on a flight planning map, or defining the waypoints with latitude and longitude coordinates. This option was discussed as a method to scan several burn piles that had been previously marked with individual GPS points. This technique may be useful if burn piles are marked with a GPS location when they are piled or burned. In this mode, the pilot can pause the flight path to hover over an individual pile or maneuver the aircraft to different angles of view. A disadvantage of this point-to-point scan method is that creeping fire in debris between piles may not be detected.

These are the most basic mission planning tools that can be applied from other commonly used flight planning software. DJI Pilot software is recommended for the Mavic 2 Dual while other software programs are more compatible with other aircraft.

Thermal image formats

The image analysis process used by Hummingbird Drones requires that infrared images be in a tagged image file format (.tiff). The infrared images captured by the Mavic 2 are in a .jpeg format; consideration was given to converting the .jpeg images to a .tiff format. However, the FLIR Lepton sensor used on the Mavic 2 is non-radiometric and the .jpeg images produced do not retain essential metadata (heat signatures by pixel) that can be used to analyze infrared images in image analysis tools. The FLIR Lepton thermal microcamera has a low sensor resolution (160 x 120)[1] and the image clarity is reduced as a result.

The radiometric thermal sensor used on the BCTS DJI Inspire 1 Pro (Zenmuse XT) captures images containing "data that can be accessed later to determine the temperature of individual image pixels within a thermal image."[2] The Zenmuse XT has greater sensor resolution (336X256) and will produce .tiff images of higher quality than the FLIR Lepton.

DISCUSSION AND NEXT STEPS

Orthomosaic mapping

Building an orthomosaic map of a scan area is not critical to the hotspot detection operation; however, having the orthomosaic map can add accuracy in georeferencing hotspots. By referencing the identified hotspot on the infrared image with the physical features on the orthomosaic map, the location can be fixed to the GPS location identified on the orthmosaic.

Several software products are available to create orthomosaic maps. The software used by Hummingbird Drones processed the images collected at each of the trial sites in less than 30 minutes. The software is quite expensive and requires a high-powered computer. As an alternative for users that don't have access to software, service providers can process a batch of images to create an orthomosaic of an area.

Some recommendations for image acquisition for orthomosaic mapping include:

- Acquire images at higher altitude, if possible; more altitude is better for orthomosaic mapping
- Have the camera positioned in nadir view
- Remove images that are blurry, are not oriented properly, or have aircraft landing gear included

Programmed flight planning vs. manual flight

A manually controlled flight may be preferable to a programmed mission when there are suspect areas of hotspots in burning debris and an operator wants to make a quick scan of that specific area. When an area contains obvious areas where debris piles have been burned, it may not be necessary to conduct a full area scan.

Manual flight may also be preferable on steep slopes where obstacles are present. On steep slopes it is important to choose a vantage point that allows the pilots a good visual line of sight for the flight. If first-person

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[1] https://uavcoach.com/thermal-drones/
[2] https://uavcoach.com/thermal-drones/#radiometric

view is used for navigation or when the pilot is monitoring the screen to detect hotspots, an observer should be present to maintain visual contact with the RPA.

If a GPS location can be recorded for each debris pile during piling or burning operations, this set of GPS locations can be passed on to BCTS for infrared scanning missions in the spring. If GPS locations of individual piles are available, waypoints can be programmed into a flight planner and the flight planner will direct the aircraft from one debris pile to the next as a semi-autonomous flight. During the flight, the pilot can pause the flight plan to scout around a suspect pile at different altitudes or capture images from different angles of view.

A programmed flight path will provide a more systematic scan of an area. When the waypoints of debris piles are not known, it may be necessary to scan the entire area. If there has been extensive burning between piles (as in the case of a broadcast burn), a programmed mission will be a better scanning option.

RPAS technology comparison

Comparing the quantifiable performance attributes of each system component is a starting point in the comparison of RPASs. However, this evaluation process needs to consider how the performance of an individual component will impact the overall system performance and deliverables. For example, flight endurance of these two systems is different and will impact the number of battery exchanges required during a mission and, thus, the overall time to conduct the mission. However, there may not be any difference in the overall quality of the deliverables (image acquisition) and the extra time may not be a concern for some missions.

The Zenmuse XT sensors used by BCTS and Hummingbird Drones have similar fields of view. This has an influence on scan coverage, flight planning (overlap required), and, potentially, the quality of images.

Continued hotspot detection trials

In the spring of 2020, researchers will evaluate a thermal image analysis process provided by an external service provider to identify and georeference hotspots. This evaluation will use images captured from the Zenmuse XT sensor of BCTS' RPAS during missions on a simulated hotspot grid, a broadcast burn, or on a pile burning site.

During these future trials, workflows for mission planning, site evaluation, and data management/analysis can be reviewed and developed.

CONCLUSION

The remotely piloted aircraft systems operated by BC Timber Sales and Hummingbird Drones, the subject matter expert, have similar performance capabilities. Both systems can capture high-quality thermal images in an autonomous flight pattern or in manual flight. This study identified a key technology gap in the thermal image analysis process; however, modifications to the image analysis process have been proposed to address this gap and enable the BCTS' RPAS to be a viable hotspot detection asset.

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