

Monitoring of Geothermal Areas Using Fixed-Wing UAV-based Thermal Imaging, Reykjanesvirkjun Geothermal Area, SW Iceland

Sydney Gunnarson¹, Daniel Ben-Yehoshua¹, Tryggvi Stefánsson¹, Kristín Vala Matthíasdóttir², Yngvi Guðmundsson², Páll Kristinnsson² and Ingi Óskarsson²

¹ Svarmi ehf., Árleynir 22, 112 Reykjavík, Iceland; ² HS Orka hf, Svartsengi, 240 Grindavík, Iceland

Corresponding author: sydney@svarmi.com

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ABSTRACT

In summer 2018, a fixed-wing UAV (unmanned aerial vehicle) was flown by Svarmi ehf. at night over a ~2 km² geothermal area surrounding the Reykjanesvirkjun Power plant on Reykjanes Peninsula, SW Iceland for use by HS Orka hf. geothermal company. The UAV was equipped with a TeAx Technology ThermalCapture Fusion LWIR (Long Wave InfraRed, with FLIR Tau2 core) sensor with 0.05 K thermal sensitivity and 640 x 512-pixel resolution and specially designed for mapping. Due to the efficiency of the fixed-wing UAV, the area was mapped in a single 20-minute flight at an average GSD (ground sampling distance) of 41 cm/pixel. An absolute temperature orthomosaic (aerial image), as well as a thermal 3D point cloud, were created using photogrammetry from the resulting radiometric jpeg images. In-situ temperature loggers placed on the ground at the time of imaging indicate an accuracy of the thermal orthomosaic of ± 1 °C. The thermal orthomosaic was georeferenced using key ground features to a high-resolution (5 cm/pixel) aerial image created with the same UAV equipped with an APS-C RGB (red-green-blue) camera. Thermal mapping of geothermal areas with fixed-wing UAVs shows high potential for cost-effective and accurate monitoring or exploration of large geothermal areas. The use of thermal photogrammetry produces both 2- and 3-dimensional datasets, whereby changes in height can be monitored in addition to surface heat expression. This time-efficient method also means that large areas can be surveyed multiple times a year, offering more spatial and temporal data for geothermal companies at a lower cost than traditional ground-based mapping methods. Repeat surveys will be conducted by Svarmi ehf. annually to create a data archive though HS Orka can track changes at Reykjanesvirkjun from year-to-year.

1. INTRODUCTION



Figure 1. An overview map of the area imaged with a UAV for this study (shown in red on the map). Satellite Imagery: Bing, 2019.

Geothermal powerplants are an important energy source in Iceland, and the demand has been steadily growing for the last decade (Ragnarsson 2010). However, monitoring and exploring geothermal fields can often be a costly and even dangerous effort in highly dynamic geothermal areas. The monitoring of powerplants and the larger geothermal areas that surround them are of importance to the longevity and potential expansion of any powerplant. One example is the Reykjanesvirkjun powerplant, operated by HS Orka hf geothermal company, on Reykjanes peninsula, SW Iceland, which opened in 2006 and is undergoing expansion currently (Fig. 1, 'HS Orka fær leyfi', 2010). However, accessing the entire geothermal field on which the powerplant sits is difficult and dangerous

for employees on the ground due to the high temperatures and abundance of boiling water at the surface and hazardous gases. Furthermore, the Reykjanes geothermal area is large (several km²) and highly dynamic, making monitoring of changes with ground-based measurements impractical and time-consuming.

UAVs (Unmanned Aerial Vehicles, or drones) are therefore an ideal solution to the issue of monitoring large geothermal areas safely and efficiently. UAVs are lightweight, inexpensive and can be fitted with many types of sensors, providing datasets in a fraction of the time (Harvey and Luketina, 2015). Development of the method of using a UAV with an infrared thermal sensor outside of Iceland provides an excellent road-map for creating datasets that are useful for modeling, monitoring and construction specifically in geothermal areas (e.g. Harvey et al., 2016; Nishar et al., 2016), though the method must be refined for local weather conditions in Iceland. The use of UAVs with infrared thermal cameras in geothermal areas is a relatively new technique in Iceland (i.e. Björnsson et al., 2019; Ólafsson, 2018), and thus the accuracy of the technique has not been systematically assessed in Iceland, nor have numerous repeat surveys been performed to evaluate the potential of creating time-continuous datasets showing changes in geothermal areas. Therefore, in a collaboration between HS Orka hf and Svarmi ehf, an Icelandic UAV remote sensing company, a project was initiated in 2018 to test the feasibility and accuracy of monitoring of the geothermal area using UAVs fitted with RGB (red, green, blue, or normal color) and infrared thermal cameras. We predict that the datasets resulting from geothermal surveys will accurately record surface temperature within reasonable error and that the method will be cost-effective for mapping large geothermal areas repeatedly.

2. METHODS & RESULTS



Figure 2. The fixed-wing UAV equipped with a thermal sensor used by Svarmi ehf to create thermal datasets at Reykjanes geothermal area in summer 2018.

2.1. Methods

In summer 2018, a ~2 km² geothermal area surrounding the Reykjanesvirkjun Power plant on Reykjanes Peninsula, SW Iceland (Fig. 1) was mapped using two custom-built fixed-wing drones, each equipped with an on-board GPS (± 5 m), one with infrared thermal sensor (TeAx Technology ThermalCapture Fusion LWIR (Long Wave InfraRed, with Flir Tau2 core, 0.05 K thermal resolution, 640 x 512-pixel resolution, with drift compensation) and one with a normal color (RGB) sensor (20MP APS-C with 13 mm lens) (Fig. 2). RGB images and grayscale radiometric jpg images (thermal) acquired during the flights were processed using Pix4D software to create RGB and true-temperature thermal orthomosaics. Thermal images were captured at night to reduce the effect of sunlight on the surface temperature. RGB images were captured on a separate day from the thermal images. The wind speed was less than 10 m/s during imaging for both datasets.

Fixed permanent ground control points were surveyed using a Trimble R10 GPS rover (± 3 cm) on the day of mapping and were used to georeference the dataset and improve the accuracy so that the two datasets could be overlain and repeat surveys in the future could be compared accurately. Before and during the mapping, iButton® temperature loggers (Maxim Integrated, $\pm 0.5^\circ\text{C}$ in the range of -10°C to $+65^\circ\text{C}$) were placed on the ground in two locations in the mapping area in order to assess the accuracy of the resulting thermal orthomosaic. The locations of the iButtons® were surveyed, and point samples of the thermal orthomosaic were taken at the locations of the iButtons® to compare temperatures.

2.2 Results

Thermal and RGB orthomosaics (aerial images) of the area were produced from the images acquired (Figs. 3) which can be directly compared to within the resolution of the thermal dataset (41 cm) due to the use of ground control points for georeferencing (Fig. 4). In addition to the orthomosaics, 3D datasets (DEMs and 3D point clouds) were also created using photogrammetry from both thermal and RGB imagery (Fig. 5). The datasets required only several hours in the field for each dataset (less than 1 day total), and

about 1 week of processing time. Specifics about the resulting datasets are summarized in Table 1. Ground sampling distances refer to the average distance between points sampled on the ground to create the photogrammetric model. RMS error represents the error between ground control points and the location of those points on the photogrammetric model, and is generally considered sufficient when it is similar to the ground sampling distance.

Table 1. Specifics of the thermal and RGB UAV surveys and resulting datasets.

Dataset	Air Temperature at time of imaging	Ground Sampling Distance	RMS Error	# Flights	Area covered
Thermal orthomosaic, DSM and point cloud	9 °C	41 cm	50 cm	2	2 km ²
RGB orthomosaic, DSM and point cloud	4 °C	5 cm	5 cm	2	2 km ²

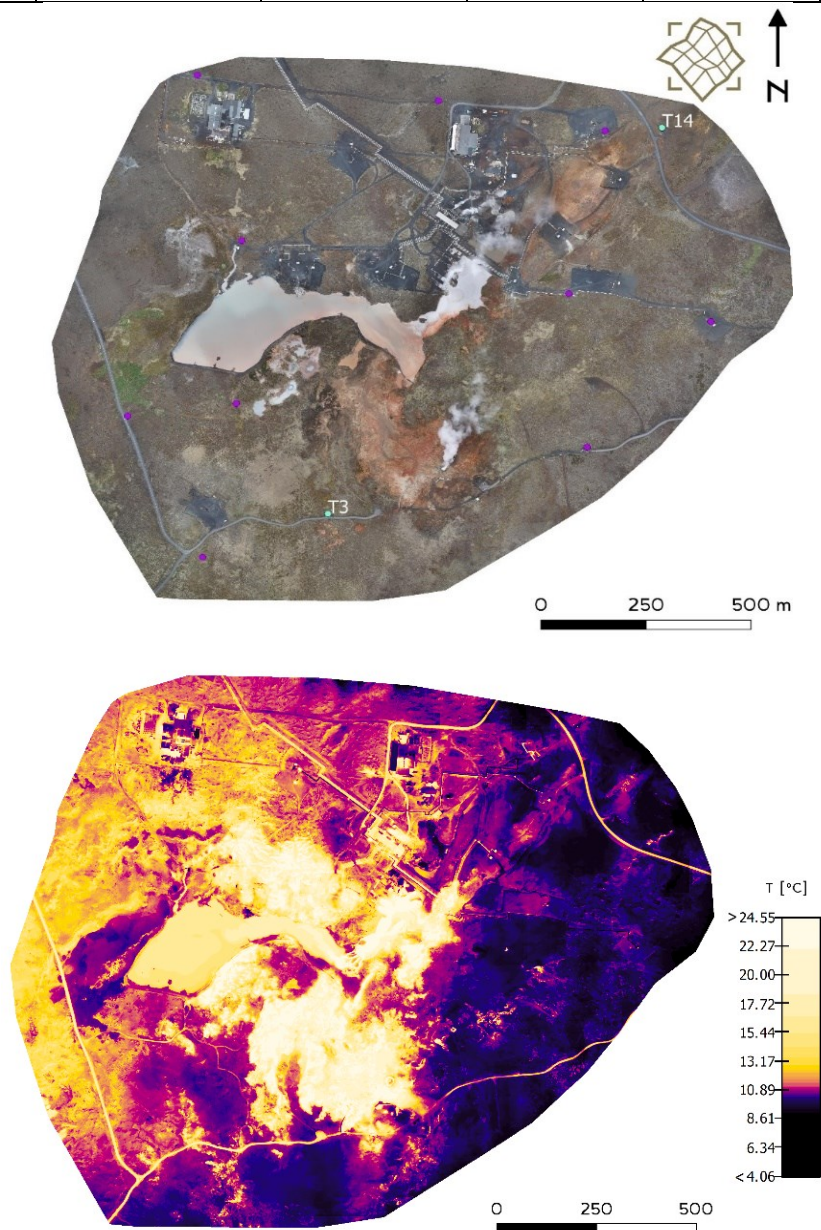


Figure 3. Upper: RGB orthomosaic of the Reykjanes geothermal area and powerplant. Purple dots indicate GPS ground control points used to georeference the datasets, labeled blue points show in-situ iButton ® temperature loggers (Table 2). **Lower:** Thermal orthomosaic of the Reykjanes geothermal area and powerplant. The temperature scale is non-linear (equal area for each temperature interval) in order to more clearly separate hotspots from background values.

Table 2. Comparison of in-situ temperature measurements and temperatures on the thermal orthomosaic.

iButton #	Avg. Temp (iButton)	Temp (thermal image)	Temperature Error
T3	11.2 °C	10.0 °C	1.2 °C
T14	11.6 °C	11.7 °C	0.1 °C

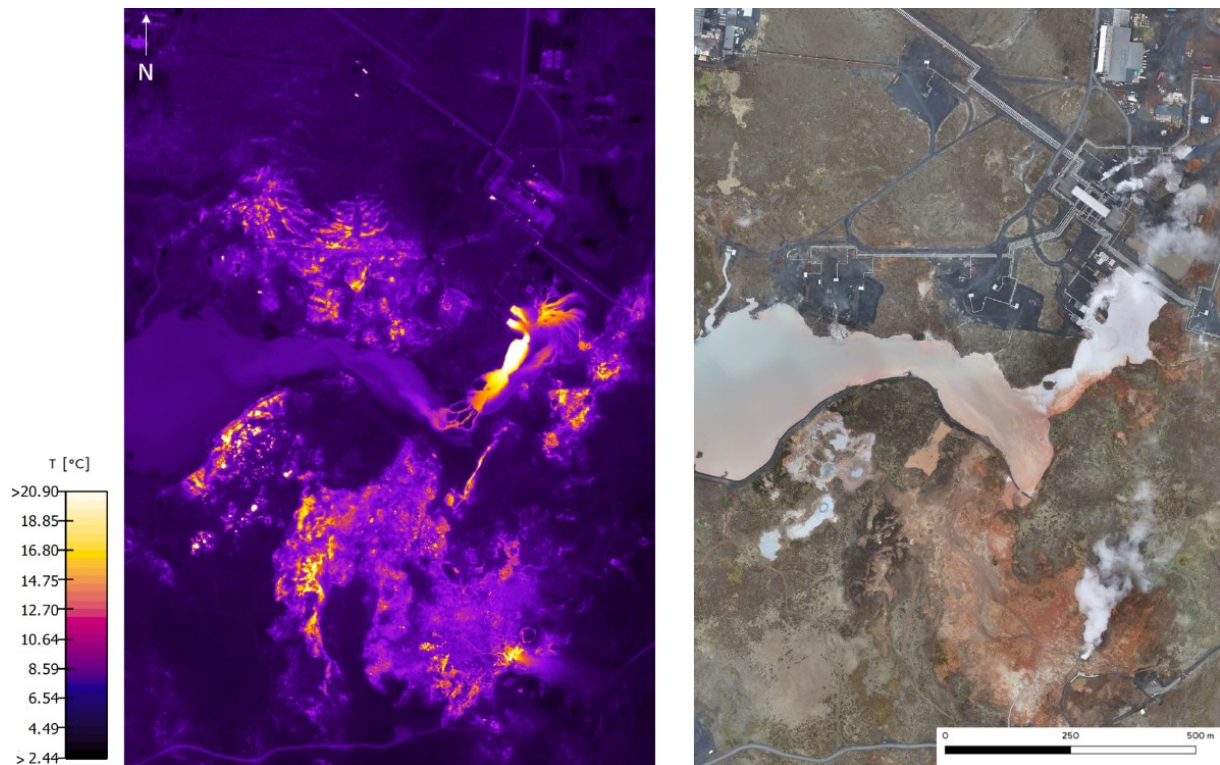


Figure 4. A section of the mapped area, showing a side-by-side comparison of the RGB (left) and thermal (right) datasets for the Reykjanesvirkjun powerplant.

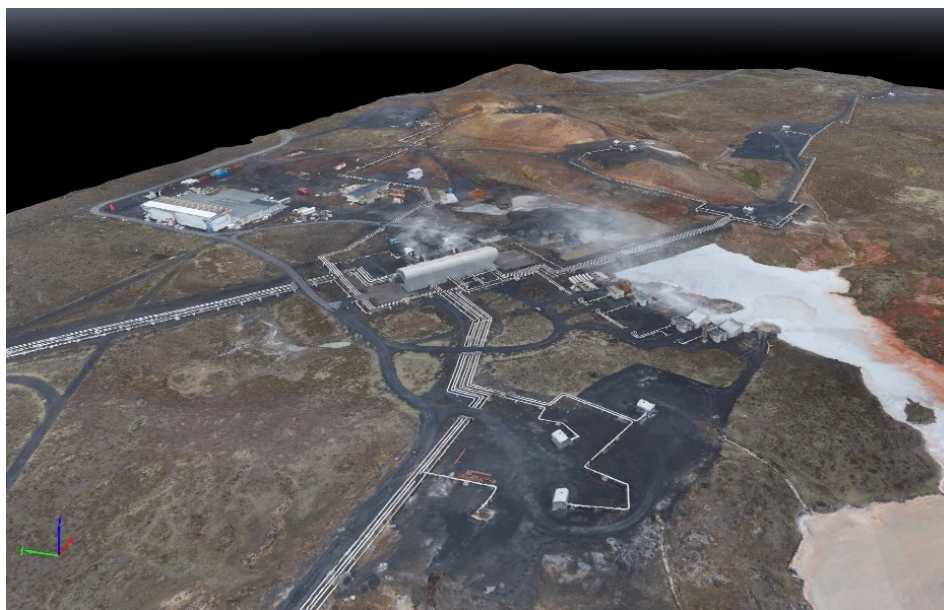


Figure 5. An example showing the 3D point cloud of the powerplant created from the RGB images.

3. DISCUSSION: FEASIBILITY OF MONITORING GEOTHERMAL AREAS USING A FIXED-WING UAV IN ICELAND

Fixed-wing UAVs have been successfully used to map large areas efficiently and accurately. Thermal UAV datasets produced from only several hours in the field covered 2 km² area is more cost-effective as well than ground measurements, providing a wealth of high-resolution data including surface temperature, aerial overviews, and changes in surface elevation (from 3D datasets). UAV datasets are particularly useful in geothermal areas such as Reykjanes, where ground measurements in the hottest parts of the geothermal area may be impossible. One obvious drawback to this method in Iceland in particular is its dependency on good weather, a rare commodity in Iceland, because UAVs typically cannot be flown in high winds or rain due to sensitive electronics on board. Fixed-wing UAVs, however, are particularly suited to handle this challenge over multicopter because they can map larger areas in a single flight, saving time and money and reducing the need for consistently good weather. Covering a large area in a short amount of time is of particular importance to the consistency and accuracy of the dataset, because environmental conditions change throughout the day which may compromise temperature readings (i.e. ambient temperature, effect of sunlight).

Although this method has been used previously in Iceland, this is the first time the accuracy of the temperatures in the thermal data outputs has been tested in a systematic way. Temperatures errors show promising results in this project for high-accuracy temperature measurements (± 1 °C) on the thermal data outputs, though these were only evaluated at two points which did not exhibit high surface heat (Table 2). Clearly, there is a need for more tests to assess the true accuracy/calibration of the of temperature values obtained from this method (Harvey et al., 2016), especially in areas of high surface heat. Furthermore, evaluation of how factors such as air temperature, wind, and humidity affect the datasets, factors that are known to affect the accuracy of thermal readings according to the infrared camera manufacturer and in the experience of the authors.

This study also presents the first-of-its-kind in Iceland to conduct repeat UAV thermal surveys at regular time intervals (yearly, in this case) to constantly monitor the geothermal area. These yearly datasets are currently being processed and results are pending. The use of fixed ground control points allows for direct comparison between the thermal and RGB datasets (Fig. 4) and future datasets in the same area. 3D datasets will also be able to be compared for assessing changes in surface height, reducing the need for costly and time-consuming GPS surveys in the area. One obvious step forward in the development of this repeat-survey method would be the development of algorithms to automatically detect changes detection between subsequent datasets, making relevant information more readily available to those using the datasets.

4. CONCLUSION

- Fixed-wing UAVs are an accurate (± 1 °C) and cost-effective method for quickly assessing changes in dynamic geothermal areas in Iceland.
- UAV flights reduce costs of monitoring and increase safety for employees by reducing the time spent in the field.
- Repeat surveys can be performed as frequently as needed, creating time-continuous datasets that can be compared. Svarmi will continue to conduct repeat surveys in the Reykjanes geothermal area on a monthly basis.
- Further improvements to this method include automatic change detection between repeat surveys and additional in-situ measurements to verify the accuracy/establish a calibration curve of the thermal datasets.

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