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UAV-Based Thermal Imagery of Hot Water and Steam Pipelines for Internal Leakage Detection, SW Iceland

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ABSTRACT

In Iceland, thousands of kilometers of pipelines transport hot water from boreholes to populated areas. Some of these pipelines are more than 50 years old, and corrosion and the rough climate can lead to leakage and thus to heat- and pressure loss. These leakages often occur inside of the insulation layer within the pipe casing and are therefore difficult to detect from the outside. A new approach was initiated to detect internal leakage through thermal anomalies on the pipeline surface. For this test project, a major distribution pipeline was surveyed at an average ground sampling distance of 2.1 cm using a multicopter UAV (unmanned aerial vehicle) equipped with both a long-wave infrared sensor (0.05 K thermal sensitivity) and a normal color (RGB) sensor. The UAV followed a GPS track over the course of a pipeline, ~20 km in total. Using photogrammetry, detailed georeferenced thermal- and RGB maps of the pipelines were created. The locations of potential leakages were sent to the responsible engineers who could then assess the pipe in a more efficient manner. Using this method, it was possible to successfully locate at least one major internal leak which didn't show any visible signs on the pipe casing. Multiple external leaks and other damage to the pipe casing were also identified using the UAV-based RGB and thermal imagery together. The main outcomes of this test project are: 1.) The method allowed for detection and location of internal leaks in geothermal pipelines which are invisible on the pipe casing, 2.) external damage to the pipes were also detected and located, 3.) the resulting thermal and RGB maps can be inspected and compared by the responsible engineers, reducing time spent in the field inspecting pipes and providing a more cost-effective and safe method for inspection.

1. INTRODUCTION

Today, many Icelandic homes rely on over-ground pipes which distribute hot geothermal water for heating. In fact, 89% of the 6.767 GWh of geothermal energy consumed in 2010 in Iceland was used for heating purposes (Lund et al., 2010). Therefore, these geothermal distribution pipes are a necessary infrastructure in Iceland, and inspection & maintenance of these pipes can be a logistical challenge because there are thousands of kilometers of pipes around Iceland. In SW Iceland alone, several thousands of inhabitants receive hot water via an insulated, 12 km long, above-ground distribution pipe (Njarðvíkuræð), operated by HS Orka geothermal company and originating at the Svartsengi geothermal plant (Ragnarsson, 2010). Built in 1977, Njarðvíkuræð pipeline requires regular inspection and repair. Finding and repairing leaks along this long pipe requires significant time spent in the field, and often leaks not visible on the surface (e.g. leaks into the insulation around the pipe), making visual inspection ineffective. For these reasons, using a UAV with thermal and RGB (red, green, blue, or normal color) cameras for inspections is a natural solution to the issue of inspecting of geothermal distribution pipelines. Since UAVs (unmanned aerial vehicles, or drones) are becoming cheaper and easier to use, fitting them with IR (infrared) thermal cameras for inspection of pipes and construction sites is now common in many places around the world (e.g. Rakha & Gorodetsky, 2018 and references therein). The benefits of thermal UAV inspection are many: several kilometers can be inspected in a single drone flight, images are geotagged from the on-board GPS so they can be quickly found in the field, and RGB and thermal images can be captured simultaneously to give more information in a single dataset. Despite these potential benefits, UAV pipe inspection using thermal cameras until recently has been underdeveloped and rarely used in Iceland and is usually limited to thermal surveys of geothermal areas (i.e. Björnsson et al., 2019, Ólafsson, 2018) as opposed to geothermal infrastructure. This study aims to explore the potential benefits and drawbacks of this method of using a UAV for thermal inspection of geothermal pipes in Iceland, using the Njarðvíkuræð pipeline and Reykjanesvirkjun Powerplant pipe inspection performed in 2017 and 2018 by Svarmi ehf. (an Icelandic UAV remote sensing company) as a case study. We predict that leaks and thermal anomalies in hot water pipes will be detectable using thermal cameras on UAVs because leaks will heat up the insulation in the pipe, and, since air temperatures are low in Iceland compared to the hot water in the pipes, these leaks will be visible on images as strong thermal gradients in the images.

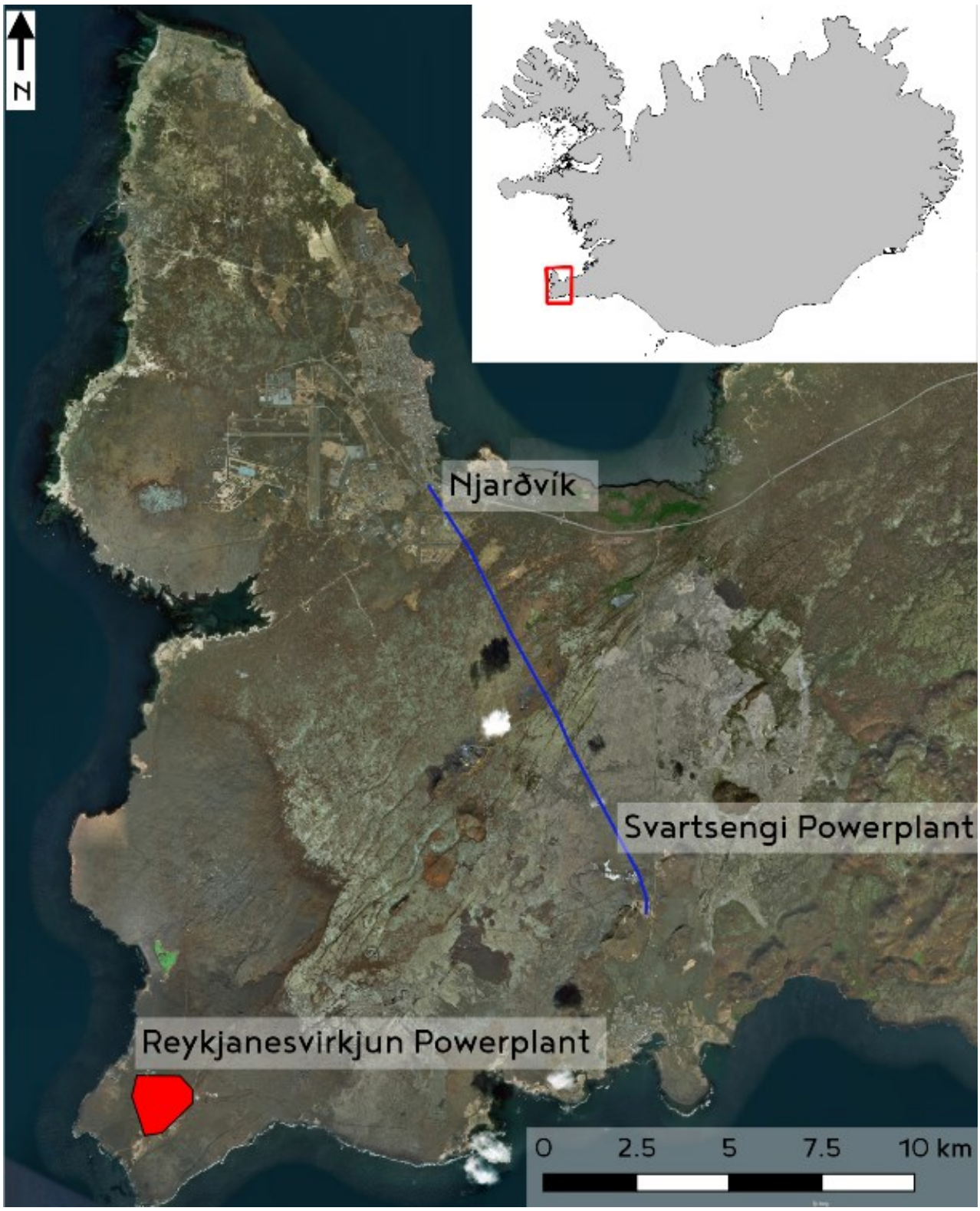

Figure 1: Overview map of the project area in SW Iceland. The red polygon illustrates the extent of the Reykjanesvirkjun Powerplant, and the blue line shows the Njarðvíkuræð running from Svartsengi Powerplant in the south to the town of Njarðvík.

2. METHODS AND RESULTS

2.1 Method

In winter 2017/2018, Svarmi ehf. (drone remote sensing company in Iceland) surveyed 12 km of Njarðvíkuræð pipeline as well as ~ 8 km of pipes circulating in Reykjanesvirkjun geothermal powerplant using a quadcopter UAV (Figure 2) equipped with both a long-wave infrared sensor (ThermalCapture Fusion, 0.05 K thermal resolution with drift compensation) and a normal color (RGB) sensor. Most of the surveyed pipeline has a shiny silver surface with a low emissivity. This means that it is a challenging target for a long wave infrared sensor as used in this survey. To conduct the survey there had to be no precipitation and windspeeds below

10m/s. In order to get an as high resolution as possible the UAV track was planned at 10 – 20 m height above the pipeline, flying at 1-3 m/s. The missions were all planned and cunducted with “Mission Planner” Software.

For both locations, grayscale radiometric jpg images from the flights were geotagged using the GPS onboard the UAV (+/- 5 m). The images were processed using Pix4D software, producing thermal- and RGB orthomosaics. At both locations, additional GPS ground control points were surveyed using a Trimble R10 GPS rover (+/- 3 cm). These points were used to further georeference the resulting thermal and RGB orthomosaics.

Thermal anomalies (steep thermal gradients at pinpoint areas on images) were detected on orthomosaics as well as individual images using in-house software. These thermal anomalies were reviewed visually by remote sensing experts at Svarmi ehf. and compared with corresponding RGB images to look for obvious signs of damage that would result in a thermal anomaly (i.e. water leakages, damages to the outsides of the pipes, etc.). Anomalies were reported to HS Orka for on-site inspection by experts.



Figure 2: The quadcopter UAV fitted with an infrared thermal sensor at Njarðvíkuræð pipeline performing high-resolution thermal inspection

2.2 Results

In order to inspect both a long-distance distribution pipeline and a network of pipes at Reykjanesvirkjun Powerplant (total of over 20 km of pipe), 5 field days were required. Specifics about the resulting thermal datasets are summarized in Table 1. Ground sampling distances refer to the average distance between points sampled on the ground in the creation of the photogrammetric model for the thermal orthomosaics. RMS error represents the error between ground control points and the location of those points on the photogrammetric model.

Table 1. A summary of the resulting thermal data products of UAV-based thermal and RGB inspection of geothermal pipes on Reykjanes peninsula at two different locations.

Project	Ambient Temp	Data output	# Flights	Field Days	Length mapped	Ground Sampling Distance	RMS Error
Reykjanesvirkjun Powerplant pipe inspection	-5 – 0 °C	Thermal and RGB orthomosaics	12	2	~ 8 km	1 - 2 cm	2 cm
Njarðvíkuræð pipe inspection	4 – 9 °C	.avi video with geotagged images, thermal & RGB orthomosaics	19	3	~12 km	2 cm	3 cm

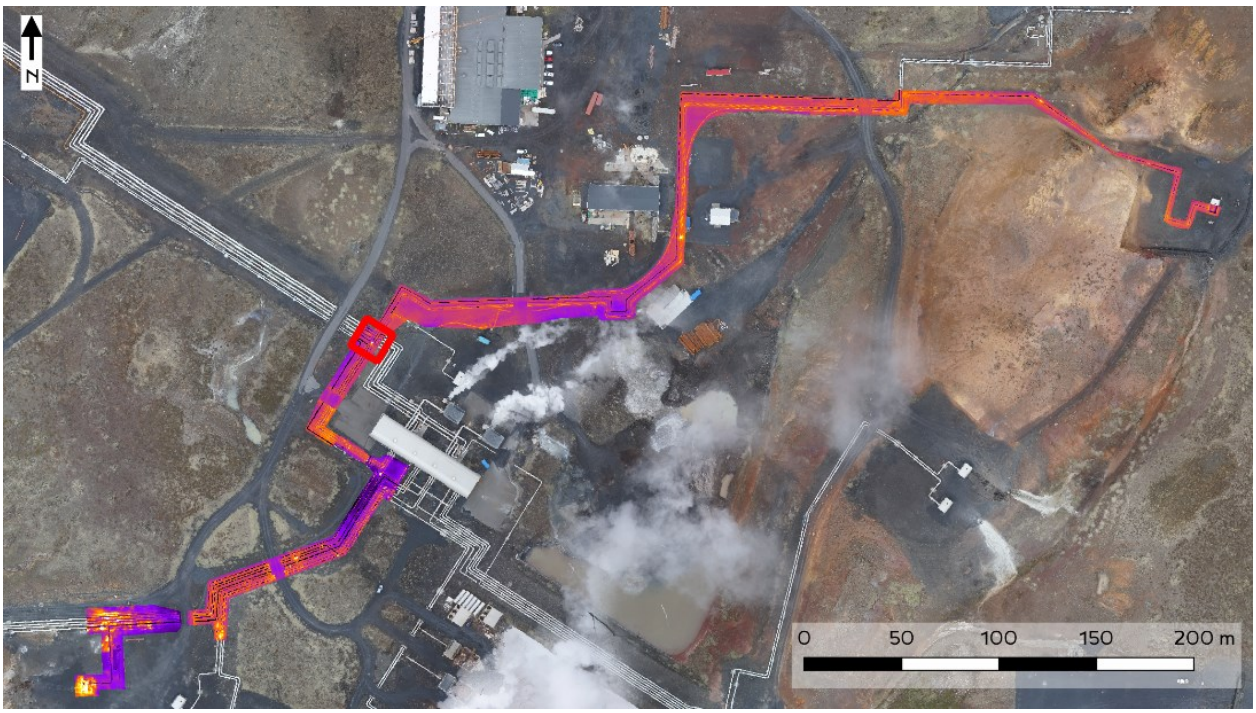

Figure 3: The map shows example thermal data of mapped pipelines within the Reykjanesvirkjun Powerplant. The color scale shows relative temperature going from black = cold to orange = hot. The red square illustrates the location of Figure 4.

In Figure 3 an overview of one of the surveyed pipelines at Reykjanesvirkjun Powerplant can be seen. The thermal raster data produced has a 2 cm ground sampling distance and can therefore be used for high resolution analysis of the pipeline infrastructure. The red square defines the location of Figure 4 where an internal leakage was identified using the thermal imagery. Note that no signs of leakage are seen on the normal color image. Thanks to accurate geolocation and this information the field engineers at the powerplant could effectively find and repair the leak.

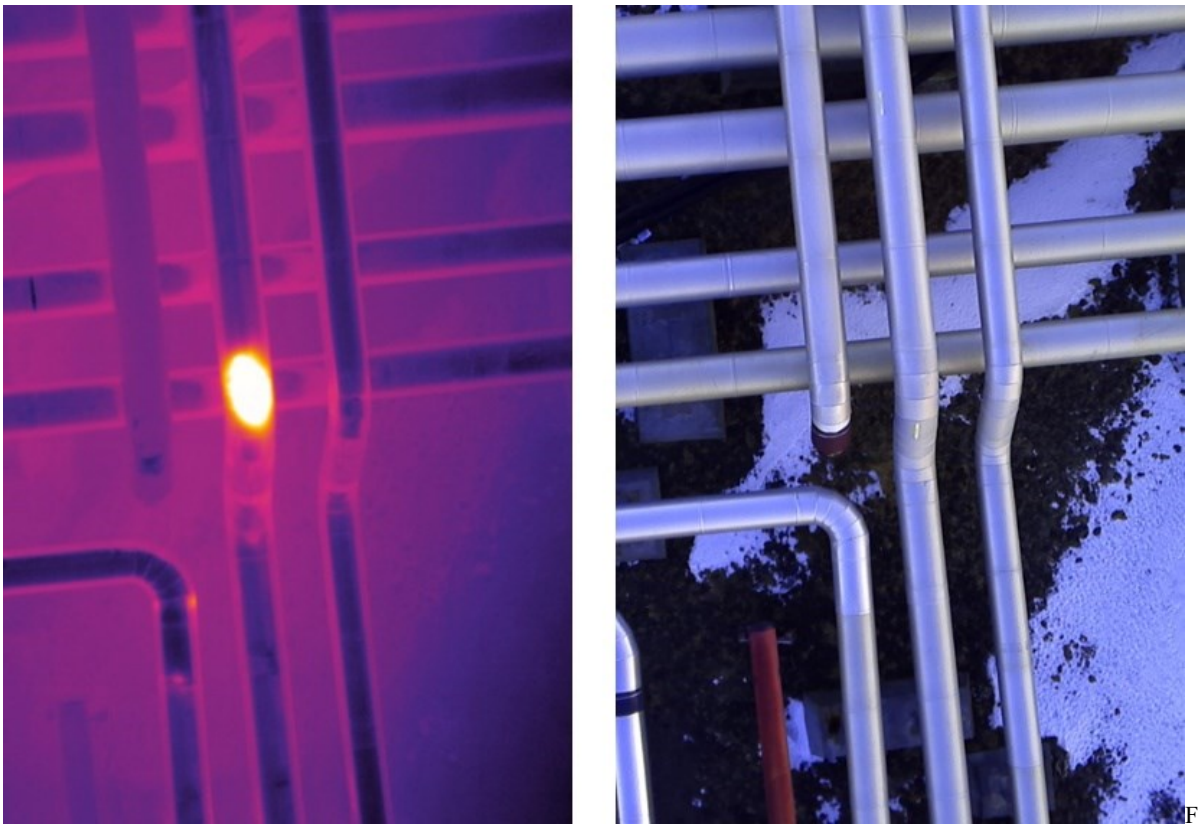

Figure 4: An internal leak identified with thermal imagery (bright spot, left image) and confirmed by engineers at HS Orka, note that it is not visible in RGB image on the right. The pipelines are 50 cm in diameter.

Another example illustrated in Figure 5 shows water escaping the pipeline appears as hot relative to the environment. Again, it is impossible or very hard to identify with only normal color imagery.

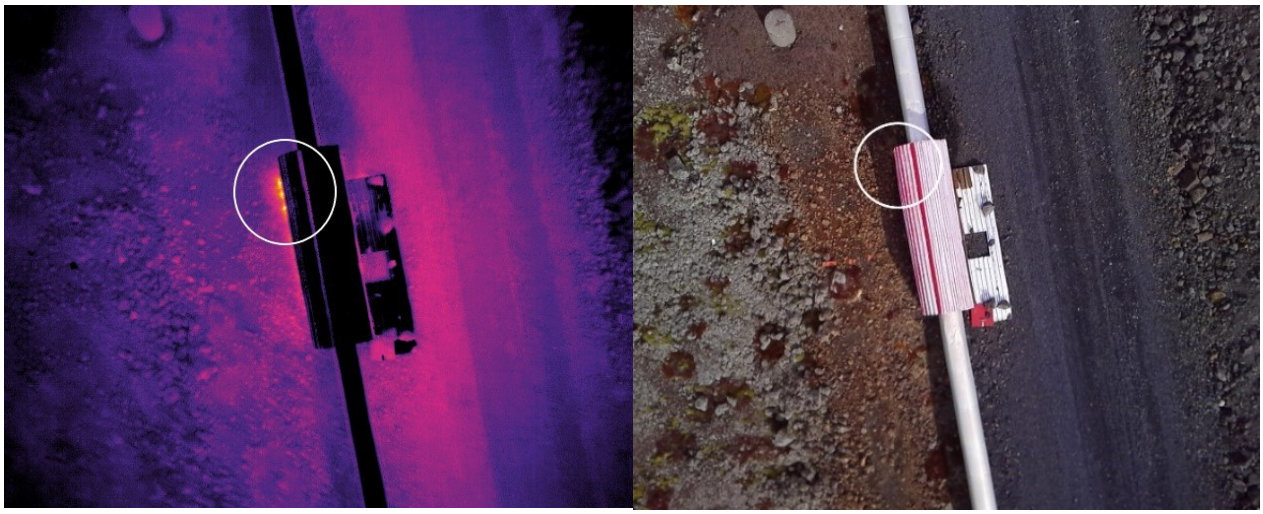

Figure 5: Successful identification of a leak in Njarðvíkuræð pipeline due to warm water spilling on the ground, visible in the thermal image (left) but difficult to identify in the RGB image (right). The pipeline is 50 cm in diameter.

Multiple thermal anomalies similar to the one in Figure 6 were found in Reykjanesvirkjun Powerplant and on the Njarðvíkuræð pipeline. Their existence was communicated to the pipeline operator. They are currently under investigation by field engineers.

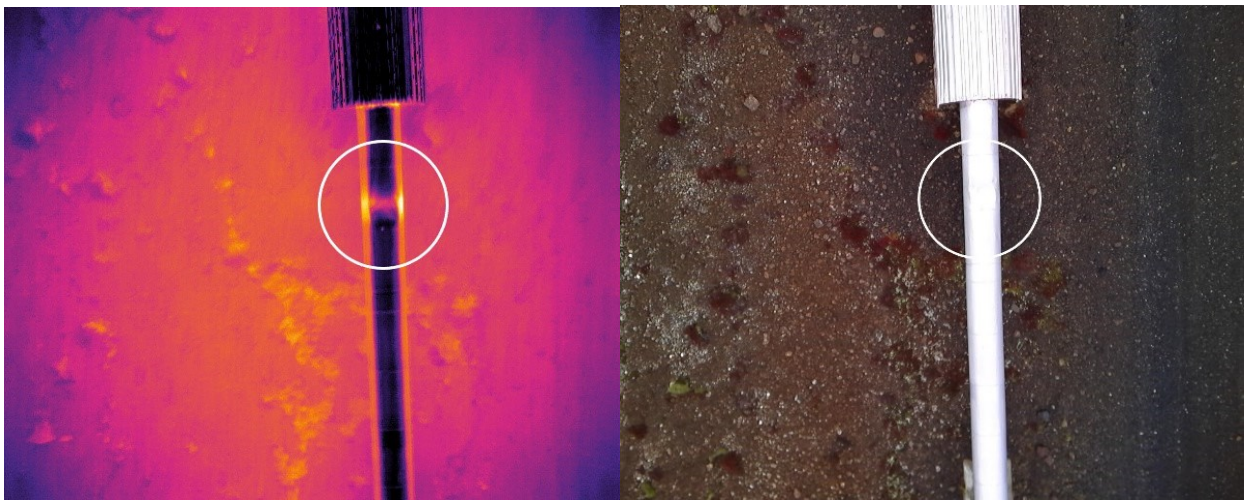

Figure 6: Identification of a thermal anomaly in the Njarðvíkuræð pipeline, with no visible damage to the outside (right image). The pipeline is 50 cm in diameter

Due to the low emissivity of the pipe surface, only relative temperatures on the pipeline can be used for leak detection. Furthermore, can be noted that on the temperature values on the sides of the pipeline can not be taken into account because they are most likely affected by reflection of the surrounding ground.

3. DISCUSSION: FEASIBILITY OF DRONE SURVEY ON GEOTHERMAL PIPES IN ICELAND

Despite the low emissivity and high reflectance of metal pipe surfaces, leaks are still detectable. This is partly due to local heating up of the actual pipe and partly due to heating up of the ground below (especially during winter when temperature differences are high). This project shows that temperature variations on low emissivity surface pipelines are detectable. However, surveying pipelines which have been painted will most likely result in more accurate temperature readings and less contamination due to reflections on the pipe.

This method is particularly useful in Iceland during the winter because low sun angles and low temperatures keep the impact of external heat sources contaminating the thermal images low.

Drones are furthermore useful for this type of inspection because these surveys can cover large areas more efficiently and especially make previously invisible leaks detectable. The surveys can be repeated at any time interval, making regular inspections more feasible. Employees of the geothermal areas will, therefore, have to spend less time inspecting the pipes, which increases the employee's safety by limiting exposure in the geothermal areas.

The most time-consuming part of the processing is the detection of leaks in the data outputs. Machine learning/automatic image classification using neural networks could be a large step forward in reducing processing cost and time and improving the quality of the results. Automatic classification of images could also provide more user-friendly data outputs (i.e. “hotspot” maps, where the user can quickly identify areas which have been characterized to have anomalous heat).

A downside to this method is that it cannot be used in heavy wind, rain, or times when steam from the geothermal area is blown into the flight path. This method should also be avoided in direct sunlight or on warm days so that heat anomalies can be more visible. Some studies suggest that high winds may influence the thermal readings of the camera due to inconsistent cooling (Björnsson et al., 2019).

4. CONCLUSION

-Temperature variations on low emissivity surface pipelines can be detected but have to be analyzed carefully.

-Previously invisible leaks can be detected with the discussed method.

-UAVs fitted with infrared (thermal) and RGB sensors are an easy, safe and cost-effective way of performing routine inspections of geothermal distribution- and steam pipelines at any time-frequency in Iceland.

-UAV thermal inspection has proven viable on geothermal pipes in Iceland, improving the efficiency of inspecting these pipes and limiting the time that employees need to spend in the field

-In this study, UAVs with fitted thermal cameras have successfully been used to detect previously unknown leaks in above-ground geothermal pipes as well as used to detect of dozens of thermal anomalies (potential leaks) in over 20 km of geothermal pipe in SW Iceland.

-Potential future work to improve this method includes machine learning to detect leaks faster and a partly or fully autonomous UAV which continuously monitors and processes the pipe infrastructure.

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