1. Overview

- Very high spatial resolution (hyperspatial) thermal remote sensing from small Unmanned Aerial Systems (sUAS) has potential to contribute to mapping and monitoring of geothermal features.

2. Pilgrim Hot Springs, Alaska

- Geothermal system located ~75km NE of Nome on Seward Peninsula.
- Shallow 90°C aquifer fed from deeper reservoirs at least ~110-150°C [1].
- DOE/EA funded project to undertake resource exploration and assessment.
- Airborne FLIR previously used to map hot springs and quantify heat flux and outflow rate (~4.7-7 MWth [2,3]).

3. sUAS Data Collection

- Aeryon Scout quadcopter equipped with FLIR TAU 2: 640 x 480 pixels covering 7.5 - 13.5 μm.
- Survey flown over Pilgrim Hot Springs on 24/7/2013: calm day with high cloud cover.
- 100m flying height = ~4cm thermal imagery, flight lines planned around extent of hot springs and thermal features mapped from ~1.5m airborne thermal imagery (flown in 2010).
- ~20mins battery life (required frequent returns to base), fully autonomous execution of survey.
- Coincident collection of calibration data at hot spring + tarp temperatures, atmospheric variables.

4. Data Preprocessing

- Difficulties with photogrammetric processing approach led to use of semi-automated mosaicking with PTGui using automatic exposure adjustment.
- Mosaic manually registered to high resolution airborne visible image using ArcMap.
- FLIR TAU 2 is uncalibrated camera: mosaic calibrated using measured temperatures of ground targets such as hot springs and black body tarps.

5. Mapping Surface Hydrothermal Features

- 4cm resolution thermal imagery provides very detailed picture of the locations and extents of hot springs and the surface outflow of geothermal fluids.

6. Hot Spring Heat Flux Estimation

- Heat budget model used to estimate hot spring heat flux and outflow rate for part of the geothermal area. Heat budget for a water body (in Watts) is expressed as:

\[
\Phi_{hot} = \Phi_{in} - \Phi_{out}
\]

where

- \(\Phi_{in}\): heat input from precipitation
- \(\Phi_{out}\): heat output from surface
- \(\Phi_{in}\): heat loss from evaporation
- \(\Phi_{out}\): heat loss by radiation
- \(\Phi_{in}\): heat loss by conduction
- \(\Phi_{out}\): heat loss by convection

- Model inputs: 1) FLIR imagery for hot waters; 2) atmospheric properties; 3) average temperature of non-geothermal surface pools.

- sUAS FLIR derived heat flux and outflow rate for part of the geothermal area from the calibrated FLIR imagery, which was compared against in-situ measurements.

7. Outcomes

- sUAS acquired hyperspatial thermal imagery mapped cm-scale hot springs and seeps, and the extents of hot water with much greater detail than airborne thermal imagery.
- NIR imagery shows changes in hot springs possibly related to surface hydrological conditions.
- sUAS thermal imagery did not provide reliable estimates of the hot spring heat flux due to significant errors in temperature calibration of the data due to use of uncalibrated camera.
- This work highlighted practical issues to be addressed before sUAS can be employed with airborne thermal imaging such as sUAS battery life, flight planning, and use of calibrated sensors.

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References