AIRBORNE INFRARED THERMOGRAPHY FOR ENVIRONMENTAL AND FACILITY MANAGEMENT OF THE ARMY NATIONAL GUARD TRAINING FACILITIES

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ABSTRACT

With all the emphases today on energy conservation and the impact of human activities on the environment, the need for efficient tools and procedures for monitoring such impacts becomes more important than ever. The progress in technologies of the thermal sensing scored tremendous advancements in the last decade and utilizing thermal surveys is proving to be one of the highest payoffs in facilities management. Most recent digital thermal sensors make it possible to detect the faintest entrapped moisture on a flat built-up roof or detect heat loss from walls in residential and industrial building structures. Trapped moisture destroys insulation and causes heat loss from the structure it is protecting. In addition, thermal surveys prove to be valuable in detecting and understanding different behaviors of pervious and impervious soil and other land covers such as wet lands and water ways.

Fugro EarthData was tasked by the U.S. Army Corps of Engineers (USACE) to utilize aerial thermal sensors to capture high quality geo-referenced thermal digital imagery over five Army National Guard facilities. The five sites were flown from different altitudes using state of the art thermal imager FLIR SC8000 and resulted in different ground sampling distance (GSD) for each of the five sites determine the best GSD for various applications. All airborne data was controlled by a GPS-supported flight management system for the purposes of accurate execution of data acquisition. The resulting product is high quality rectified and geo-referenced thermal imagery that is fully compliant with the ASPRS accuracy standard. Field temperature measurements were also compiled to aid the interpretation.

INTRODUCTION

Military installations are an ideal environment for applying thermal aerial sensors for the following reasons:

1) Traditionally, military installations have many insulated large flat built-up roofs. With time, the roofing materials on these structures may give way to harsh weather conditions causing moisture or water to reach to the insulation materials. Insulation, however, serves as a sponge-like medium that can hold water, allowing moisture to go undetected. Wet insulation materials act as powerful thermal conductors allowing heat or coolness to get into or out of the insulated buildings causing not only a source of unwanted energy loss but also damage to the roof structures themselves. Annually, these flat built-up roofing systems require large expenditures of resources for maintenance, repair, and replacement. Using infrared thermography to detect moisture entrapped in flat built-up roofs has proven to be one of the most effective applications of infrared technology. (Abdullah and Kreighbaum, 1999)

2) Thermography works the same way in identifying areas of heat loss in buried high temperature hot water (HTHW) pipes and steam lines.

3) Military facilities usually extend over vast amounts of land which envelop various land covers and natural resources that are essential to the environment and the earth's ecological system. Thermal Infrared survey can provide effective means to monitor and analyze such natural resources.

SCOPE OF THE PROJECT

Under contract with the USACE (St. Louis District), Fugro EarthData was tasked with completing thermal infrared surveys of five Army National Guard training facilities located at different parts of the United States. The USACE in collaboration with the Army National Guard wanted to test the effectiveness of the latest thermal sensor technologies as a non-intrusive investigative tool for facilities monitoring and management. The contract also specified different GSD to be investigated to determine the most effective thermal imaging resolution for studies concerning facility resources management.

AERIAL DATA ACQUISTION

Subsequent to project design and flight planning, the five sites were flown using the FLIR SC8000 imager with 1024x1024 pixels array and 25mm focal length lens resulted in the flying parameters for each of the sites as shown in Table 1.

Table 1: Flight Parameters for the Aerial Thermal Acquisitions

Site	Area (sq km)	Flying Altitude (AMT) (m)	Resulting GSD (m)	Number of Flight Lines
Camp Blanding, FL	116.6	1,387	1.0	29
Camp Fogarty, RI	2.0	695	0.5	10
Camp Mabry, TX	1.9	695	0.5	9
Camp Navajo, AZ	44.4	975	0.7	32
Camp Robinson, AR	51.7	975	0.7	40

The data were collected during the cold evening hours between 2 a.m. and 5 a.m. using a Global Navigation Satellite System (GNSS) and Flight Management System (FMS) equipped Piper Navajo Chieftain. The aircraft flew at the altitude given in Table 1 for each of the five sites.

FIELD DATA ACQUISTION

Along with the aerial data acquisition, another data collection operation was simultaneously executed in the field. A field crew with sensitive handheld thermal reading instruments was dispatched to the field during the aerial acquisition phase. The task of the field crew was to collect enough temperature readings for different ground cover types so aerial thermal data can be examined for reliability and accuracy. About 40 to 60 temperature readings were recorded for each site representing the following ground cover types:

- Deep water bodies such as lakes;
- Shallow water bodies such as streams, marsh land, etc.;
- Pavements;
- Dirt roads;
- Vegetations;
- Building roofs;
- Metal structures.

Each temperature reading sample was recorded along with GPS locations and necessary metadata concerning the reading such as weather and ground conditions.

SENSOR TECHNOLOGY

Fugro EarthData used the recently developed thermal sensor technology by FLIR Systems Inc. as a response to demands by science and defense communities to be used for scientific applications and security intelligence. The SC8000 (Figure 1), a high definition (HD with 1,024x1,024 pixels) cooled system, operates in the Mid-wave range of the infrared region of the electromagnetic spectrum between 3µm and 5µm. The sensor captures data with a dynamic range of 14-bits at a rate of 128 full frames per second (or 200 megapixels per second) using 16 channels readout. Such high sensing speed provided convenience and efficiency in the aerial acquisition task where sensor speed plays great role in the success of the aerial mission. A fast lens with f-stop of 4.0 and a focal length of 25mm provided a Field of View (FOV) of 40^0 coverage was utilized with the sensor. The sensor employs unique technologies such as the "Built-In NUC" (On-camera Non-Uniformity Corrections) and the "On-Camera Cal" (On-camera radiance and thermographic calibration) which makes it one of the most accurate sensors available for this task.

- Maker: FLIR
- Model: FLIR SC8000 High Resolution Imager
- CCD Array size: True1024x1024 without image dithering or stitching
- Pixel size: 18 um
- Full Frame Rate: 132 fps
- Dynamic Rage: 14 bit
- Sensor Cooling: Split-Stirling Closed Cycle
- Spectral Range: Mid wave Infrared (3-5 µm)
- Thermal sensitivity: 0.0068º C (<25 mK)
- Noise Equivalent Temperature Difference (NETD): 0.0068º C (<25 mK)

Figure 1. The FLIR SC8000 series Thermal Imager (image courtesy of FLIR Systems, Inc.).

DATA PROCESSING

After completing the aerial data acquisition for each site, the raw thermal imagery was immediately reviewed by experienced Fugro EarthData staff via the internet for quality and completeness. In this on-line live session, the staff communicated to the field crew their observations and discussed needs for corrective actions, if any, while the crew was still in the field. FLIR processing software, the "ExaminIR" was utilized for the initial review and the export of the raw thermal imagery. Upon receiving and processing the GNSSS data, a flight index was generated for each site. Fugro EarthData used the flight index to identify the locations of all collected frames from which suitable frames were selected, and then utilized a combination of proprietary software and ArcGIS tools for the process of geo-referencing and mosaicing. The geo-referencing process was based on extracting ground control points from existing accurate digital color ortho photo with map scale of 1:1,200 or 1"=100" that were available for each of the five sites. The resulting horizontal accuracy of the mosaic is found to be better than 4 pixels as RMSE. The resulting mosaic was then cut into tiles according to a specified tile layout for each site.

RESULT ANALYSIS

Although the contract did not call for final data interpretation and analysis, Fugro EarthData conducted preliminary analysis on the geo-referenced tiles to determine the suitability of the delivered product for the following investigations:

1) Detect Moisture-related Problems in Roofs:

The thermal tiles were analyzed to identify the sensor's capability in identifying potential problems in flat built-up roofing systems caused by entrapped moisture or deterioration of the building materials. Figure 2 demonstrates the details in the thermal signature of a building roof. Some joints in the roof can be identified due to the presence of moisture under the roofing materials as shown in the bottom half of the figure. Such identification provides a nondestructive method for the maintenance engineers in monitoring and evaluating the conditions of roofs of buildings that fall within their jurisdictions or responsibilities. Field investigations should be accompanied by such analysis in order to further validate the results from aerial thermal surveys before reaching a final conclusion.

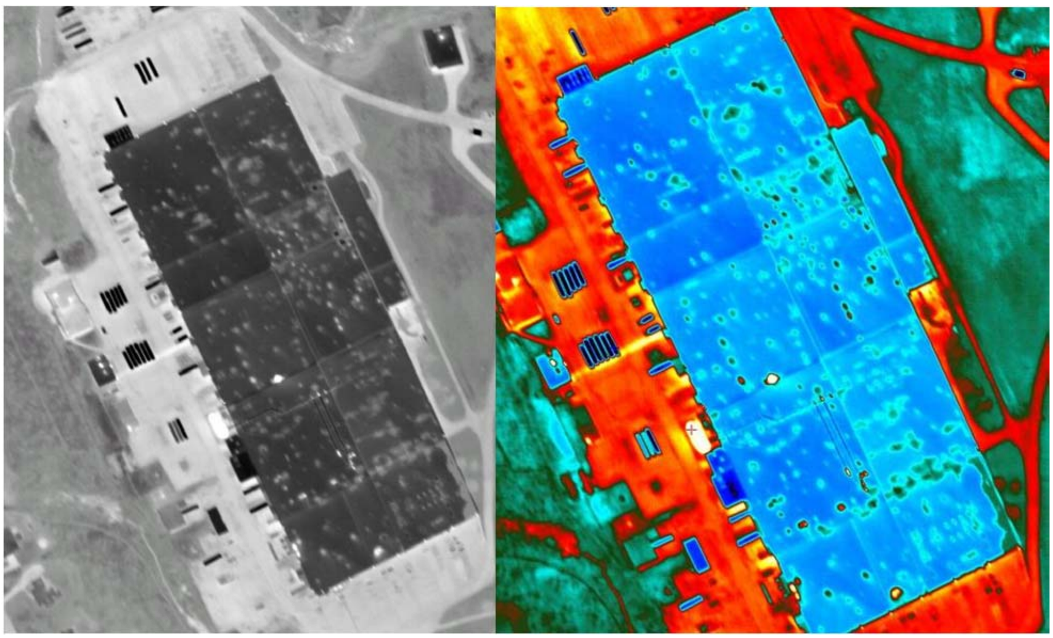

Figure 2. Thermal survey for roof inspection, Left: Panchromatic thermal image, Right: Colorized thermal image.

2) Evaluate Energy Efficiency Problems:

In addition to evaluating moisture leaks into the roofing materials, imaging thermal survey products can be used to evaluate the quality of insulation around a building structure. In Figure 2, the patterns of thermal signature (tonal differences) appears in the thermal image of the roof surface which often provides hints about the source of excessive heat loss caused by poorly constructed roof features such as skylights, roof vents, exhaust systems, etc. Roof ventilators may represent a considerable waste of energy if they are operated unnecessarily or inappropriately. Examples of such potential problems are the two ventilations elements appearing toward the center and the lower end of the building in Figure 2.

Another evaluation of energy efficiency is the detection and inspection of underground utilities for potential energy loss. In Figure 2, an underground utility emitting significant heat is discernable running perpendicular to the building midway along the parking area on the left side. Aerial thermal imagery can provide a valuable diagnostic tool to identify potential subsurface utility issues. This data acquisition method can quickly pinpoint utility or insulation leaks for further field investigation minimizing unnecessary excavation and service disruption.

3) Monitoring and Evaluation of Water Resources:

The products show great potential for the thermal aerial survey in delineating water resources of different sizes and shapes. In color imagery, the signature of streams and shallow water can easily blend with the adjacent area due to similarities in tonal appearance with the surrounding environment caused by reflections or shadows. However the thermal signature of a tiny stream spiraling between vegetation can be easily spotted as the thermal signatures of the stream and surrounding environment do not influence each other. In Figure 3, the streams network feeding into the pond is clearly visible in the thermal image despite the presence of vegetation surrounding these streams.

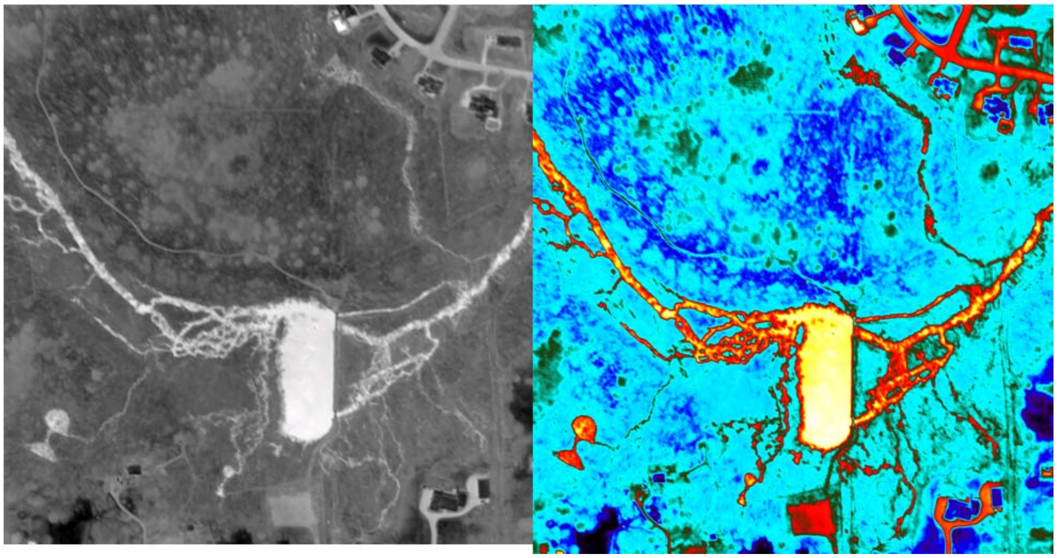

Figure 3. Thermal Survey for water resources delineation (left: Panchromatic thermal image of a pond Right: Colorized thermal image).

4) Environmental Analysis:

The data clearly demonstrates the high potential of using the delivered product for engineering and environmental planning. Delineation of pervious versus impervious soil can be easily achieved in a fully automated way using the digital image classification techniques as illustrated in Figure 4. In Figure 4, delineation of pavements, parking lots, buildings, and other man made features can be easily recognized and separated from the unpaved areas as the thermal signatures of these man made structures are distinct from the vegetated or other undisturbed ground.

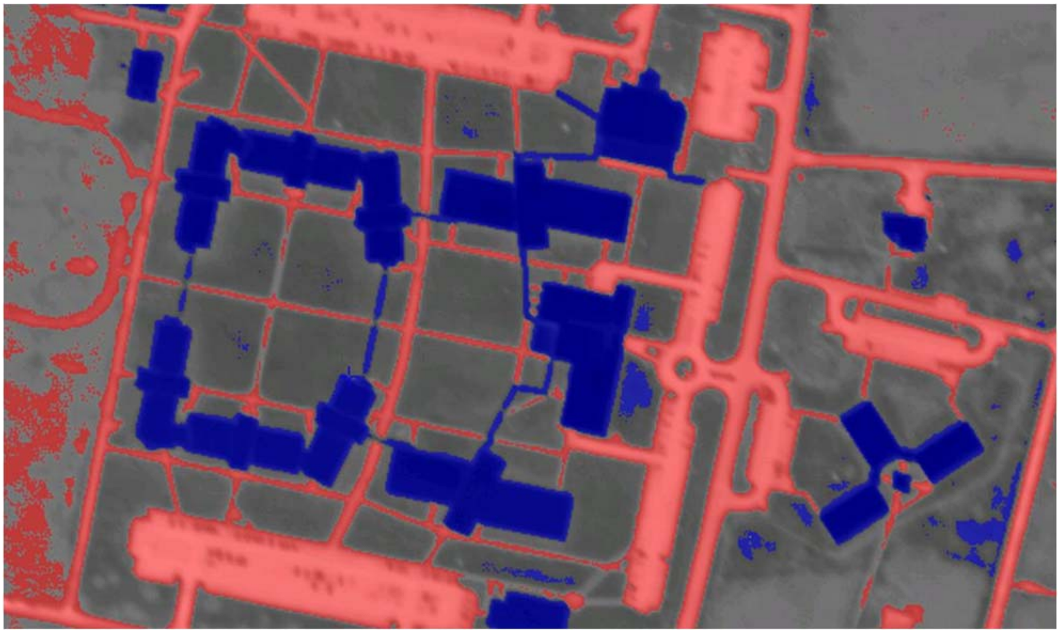

Figure 4. Thermal Survey for Engineering and Environmental Analysis – Classified thermal tile with 50 cm GSD.

5) Lake Morphology:

The delivered data revealed invisible details about the morphology of water bodies such as lakes and ponds. Figure 5 gives a side by side comparison of what a geospatial data analyst can see when looking into two data sets. The left side of the image portrays the natural color day-time imagery and the night-time thermal imagery is portrayed on the right. It is evident that thermal survey can be valuable to engineers and scientists studying subsurface environment of still and deep water bodies. At the time of publishing this paper, there was no in-field independent environmental analysis report for the lake available that could be used to verify or to recognize the details that appear in the thermal image of the lake. It is the intent of the contracting agency to pursue further analysis and field investigations to determine the nature of such details.

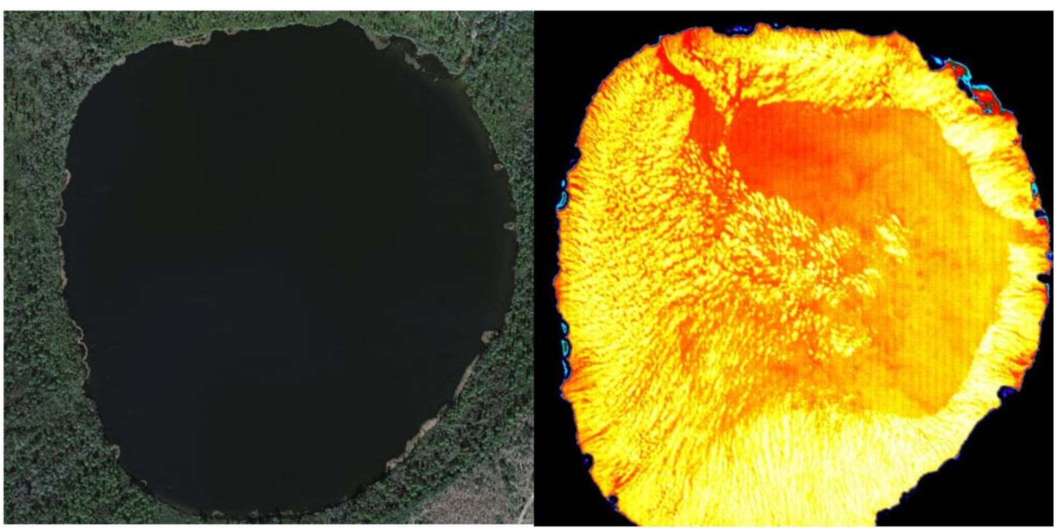

Figure 5. Thermal Survey for Lake Morphology (Left: natural color day-time imagery, Right: night-time thermal imagery.)

RECOMMENDATIONS AND CONCLUSIONS

Several recommendations are offered based on the results of this study:

1. The quality of the thermal geo-referenced aerial imagery has the potential to be used in several engineering and environmental analysis as a non-intrusive investigative method.
2. For detailed engineering applications such as roof and building inspection, higher resolution may add to the quality of the interpretation and analysis. A GSD of 50cm or better should be used for such applications.
3. For environmental and natural resources surveys and monitoring, medium resolution (GSD of 70cm to 1m) is sufficient.
4. In order to fully and efficiently utilize the results of the thermal survey product, thorough field investigations are needed to further explain the finding from the thermal survey.
5. Conducting similar surveys during differing climate conditions may add to the effectiveness of the thermal survey for some applications.
6. The use of the flight management system, based on GNSS, contributed greatly to the success of the survey, and prevented unnecessary data collection and ultimately resulted in cost reduction.
7. The use of existing color ortho imagery to geo-reference the thermal mosaic resulted in a very accurate product without the extra expenses that would be spent for ground control survey.
8. A thorough knowledge of the physics of remote sensing and thermal sensor technologies and capabilities is essential to achieving the best quality thermal imagery and derived conclusions

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