NEW AIRBORNE THERMAL INFRARED PHOTOGRAMMETRIC APPLICATIONS AND SENSORS FOR MOISTRURE DETECTION

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ABSTRACT:

Thermal infrared sensors were commonly used for monitoring urban heat effects almost 15 years ago. Meanwhile the new multi- and hyper-spectral space-borne sensors offer this data too, therefore the airborne applications became rarely since the last 10 years. Common for all ThIR Sensors is a poor ground sampling distance. Newly developed small sensors are not adjusted to be used for Remote-sensing purposes. Beside this, their geometric resolution is still on a very poor level. In most cases, these sensors are designed for military application and not for absolute determinations. This means that calibration has to be done before such systems can be practically used. A new market was born to determine thermal losses of buildings, which is just a bigger scale than the urban heat applications were. New is the analysis of evaporation–heat effect due to water distribution in construction sites. This remotely sensed technology can be combined perfectly with humidity sensors like TDR and others. Power lines can be used as a humidity sensor as well which will be shown up in the last chapter.

1. PHYSICS OF IR THERMOGRAPHY

The basic principal of thermography is, that any object emits electromagnetic radiation as long as it is above the absolute temperature (-273.15 °C). There is a clear defined physical relation between temperature on its surface and its spectral distribution and intensity of radiation. By analysing this temperature of this object can be measured touch less – a real remote sensor.

Electromagnetic radiation in the IR band is not visible for human eyes since the wavelength is longer and the frequency lower. Thermographic cameras use detectors sensible for these spectral bands and in many cases filtered in smaller sub bands. Following on the last visible red coloured band, infrared or ultra red significant has longer wavelength. Visible bands are 0.4-0.65 µm followed by Near-IR (0.65-1 µm), Medium-IR (1-7 µm) and Long-IR (7-20 µm). This long infrared band is also called thermal band that finally the one used for thermographic applications. Beside the absolute temperature, detection of thermal gradients is of interest, means to detect spatial differences of radiation on the objects surface. Thermal Infrared cameras map the surface temperature and show gradients. Thermal radiation is initiated by molecular motion, which penetrates the material of the object. The material itself can absorb heat and emit thermal radiation. The heat transport capability of the material can effect to be defining it as an isolator or vice versa as a heat-path. The heat penetration coefficient describes material specific characteristic. Different materials have also different heat-buffer capacities. This finally is the effect of urban heat, that a city is a “battery for heat” loaded during the day and emitted during nighttimes. Today’s most frequent application with Thermography is used for the localization of bad isolation or thermal bridges of buildings.

The equation for material characteristics is:

$$b = v\,?\cdot ?\cdot ?$$

b = heat penetration coefficient [J/m^{2}Ks^{0,5}]
p = density [kg/m³]
? = heat conductivity [W/(m · K)]
? = specific heat capacity [J/(kg · K)]

Heat effects also result in other parameters, especially the evaporation. Water needs heat to evaporate and to do so, the temperature on related parts of an objects are reduced. This effect makes Thermography to a spatial humidity detector that can be nicely combined with continuously logging sensors.

2. AIRBORNE THERMOGRAPHY

Two aerial missions using a Raytheon ExplorIR Camera monitored the city of Sinsheim in the southwestern part of Germany. An observation in the nighttime and one in the early morning aimed to detect the urban heat spots in a resolution where satellite data cannot compete. The different effects of buildings, streets, and areas of high exchange rates due to wind can be extracted out of this data easily. Using this high-resolution data, small parcelled structure can be perfectly analysed. The comparison of the flights furthermore enables the estimation of heat accumulation effects by urban fabric. Urban heat is based mainly on three effects:

- The urban fabric that accumulates solar energy and operates as a thermal buffer
- The emitted heat of residences (air-condition, heating...), industry and traffic
- The limited wind stream between urban structures

In case of this camera has a sensor size of 320 x 240 pixels only, a huge number of single images have been taken and finally georeferenced to an entire mosaic. In fact, a video-sequence-technology was used in order to determine the basic temperature change during a single mission. A drift was computed and then a back-calibration done for all data.

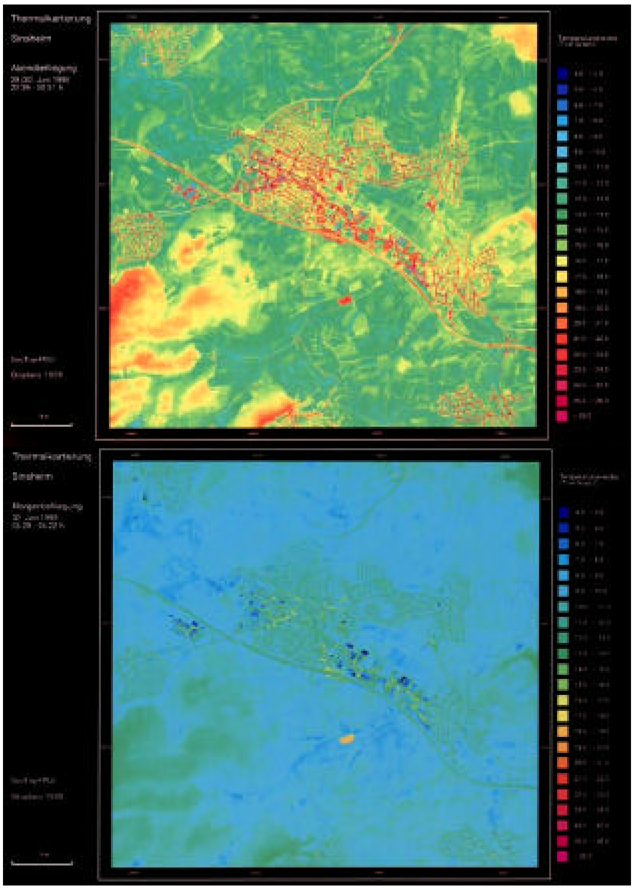

Figure 1: ThIR missions over Sinsheim at two different times, the image above shows the mission around 23:30, the image below in at 4:30

The thermal resolution is 0.15°C and the range -10 to +30°C. The georeferencation was done based on Orthophotos where structures could be identified. Some thermal-key-objects e.g. water bodies and exhaust-tubes, were used as GCPs. In cases of lack of identification, image to image geocoding was done and then these mini-blocks adjusted by reliable GCPs. The final Ground Sampling distance was 4 m. The images above show the accumulation effect nicely. The lake in the lower middle is the strongest emitter. Urban structures emit IR radiation in the night while in the morning only a few spots show a higher radiation than the environment. Some objects already accumulate radiation in this early morning time and can be detected as cold spots.

3. IRRIGATION MONITORING

Another airborne project was done for determining water irrigation of fields during night. A night mission with a ThIR Camera was performed for monitor agricultural areas close to Hassloch in southwestern Germany. Beside the heat differences, the structure of the fields can be identified. Important task was to detect the irrigated fields and the pattern that are just under irrigation. This temperature difference is very easy to identify and can be visualised easily. Not only the wet-cold and dry-warm single parcels can be clearly separated, also the place of the irrigator can be detected well. Using satellite-data and their resolution of 30-100 m / pixel, the small fields could not be recognised as good as data of the camera did. After geo-referencing of the images to a mosaic, image analyses typical for remote sensing software's were able to extract an irrigation map automatically. These results applied in GIS datasets can assist in monitoring agricultural activities and help in planning sustainable development towards an ecological farming.

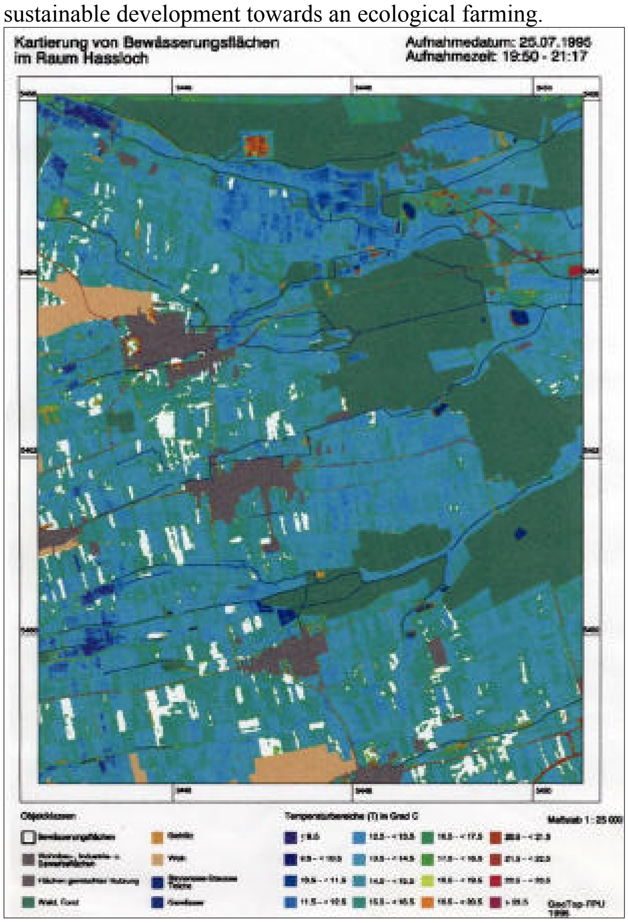

Figure 2: GIS output of a ThIR mission refined by cluster analysis to detect irrigation areas. Irrigation areas are drawn in white.

4. BUILDING OBSERVATION

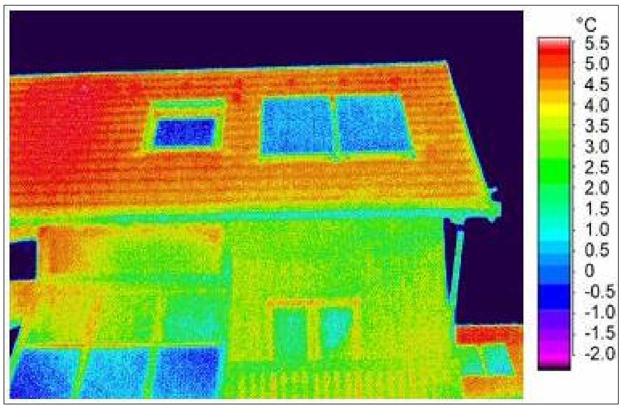

Figure 3: ThIR image of a building; solar thermal panels can be seen as cold blocks on the roof

Thermal infrared cameras nowadays are mostly used to monitor thermal emission of buildings. For saving energy, good isolation is required in order to reduce heating costs. Some parts however are difficult to isolate and can be detected as heat-bridges. Beside that, moisture transport becomes a serious problem due to cold and hot spots. Higher humidity can be detected as inhomogeneities in the thermal images. Zones of moisture transport are colder due to evaporation processes.

5. HEAT PIPE MONITORING

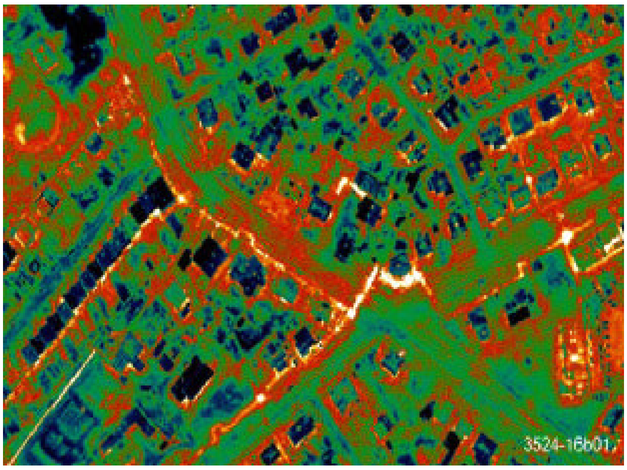

Figure 4: Monitoring of heat-pipes to detect defects in the isolation

Monitoring of pipelines is a common application where ThIR Cameras are used. Anomalies in the radiation can detect defects in the isolation or even leakages of the pipe. Sharp anomalies typically show isolation defects while diffuse and wider spots can indicate leakages. This can be applied also to water pipelines while running of liquids might indicate evaporation processes that show up cold-spots.

6. ANALYSING INHOMOGENEITIES

A new application that requires very high-resolution data is the determination of construction sites e.g. bridges, roads and others. This typically is performed using helicopters or large tripods. GSDs of few cm are possible and assist to detect inhomogeneities visible by thermal differences. Like this, cables, drainages, non-homogeny concrete and others can be detected. ThIR Technology as be found as ideal to assist in monitoring the stability of bridges and roads.

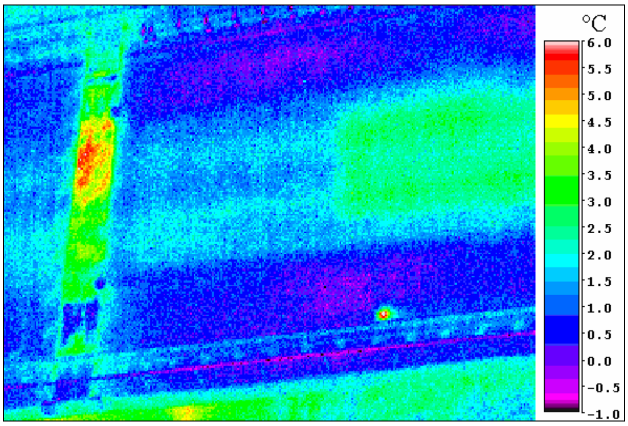

Figure 5: Detection of inhomogeneities of a road surface on a bridge

This inhomogeneity visible in the thermal image helps to identify e.g. where water penetrates the surface or bad concrete influences the heat transport. In addition, cables and other technical infrastructure can be identified with this technology.

7. WASTE DISPOSALS

The biggest risk of waste disposals can appear if the "internal reactor" produces too much heat and accelerates the chemical processes, which then can lead to dramatic explosions. Badly monitored dumpsites cased big disasters in the past. Monitoring these waste disposals with a ThIR Camera can assist in an early warning for defending such risks. Especially the combination of sensors that continuously measure the moisture conditions and regularly made thermal observation give a good database for decisions.

Humidity is the main regulator in the internal chemical process. Drying out of a dumpsite reduces the risk for uncontrolled reactions. However, today the dumpsite gas (mainly Methane) is used as an energy resource. Due to that, water has to be infiltrated in the right amount to the right place. Monitoring is required on a high redundant level to protect against manmade disasters.

TDR-Sensors, which detect humidity by dielectrically property changes, allow to control wider parts than other sensors. This innovative technology is applied on several dumpsites in Germany. These long cable-sensors measure only within a few cm distances continuously while the ThIR Camera can observe the entire site at a discrete time. Their combination is synergetic and recommended.

Figure 6: Installation of TDR Sensor cables on a dump-site to monitor the sealing layer.

8. MONITORING POWER LINES

There are many aspects that make monitoring of power lines useful. Beside classical monitoring which is done by manual aerial inspections with helicopters, aerial photographs and Lidar, also thermal measurements take place to detect faults in the installation, mainly at the cables and the isolators.

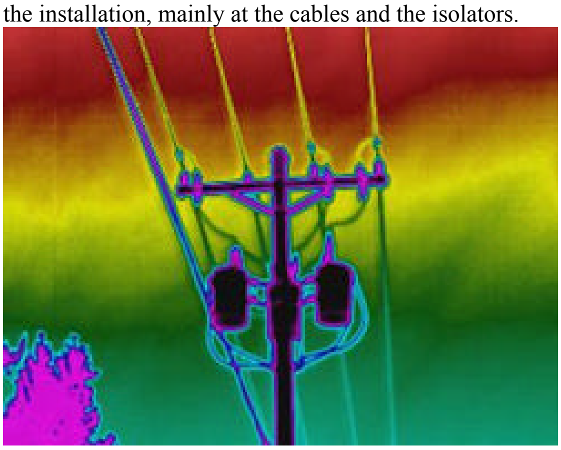

Figure 7: ThIR image of a powerline-pylon with isolators [www.raventr.com; accessed on 1.4.08]

In classical inspections, faults of isolators or cables are detected by visual observation. In some cases, systematic aerial surveys with direct orientation facilities enable automated orthophoto generation to measure directly objects of interest. Lidar frequently is done to measure the sag of the cables as well as the trees and bushes that have to be cut in order to remove risks for the lines and/or the environment. In addition, people can be affected if a cable is contacted by vegetation. With ThIR, anomalies can be seen easily which might indicate problems in the wire. Especially under humid conditions, everyone can detect corona-effects even acoustically.

The powerline itself can be a remote sensor for the humidity condition in its closer environment. The research centre of Karlsruhe set up an interesting project.

8.1 Free-Line-Sensor

Evaporation and precipitation at the earth's surface are key elements of the hydrological cycle and need to be considered in weather forecast and climate models. The distribution of water vapour in the atmosphere and its development over time is one of the most important factors in connection with precipitation processes. A number of properties including soil moisture, which affects the energy balance, controls the availability of atmospheric moisture for precipitation and thus the evapotranspiration processes. In addition to studying these processes, soil moisture monitoring can help to more accurately assess the ripeness of plants and estimate the time of harvest and expected profit, and can warn against the risks of e.g. inundation or slope failure, as well as being a reference method for the calibration of satellite data. It could be used for monitor the water-conditions in forest that could be applied ain a for forest-fire warning system.

Soil moisture is often measured locally with in-situ sensors forming point measurements, like fork probes, which use time domain reflectometry, TDR, and frequency domain reflectometry, FDR, techniques (Topp et al. 1985) and others. However, all techniques reflect strong spatial and vertical variability due to the heterogeneity of most land surfaces and are difficult to extrapolate to a larger scale. Soil moisture results deduced from satellite backscattering data describe the moisture at the surface and need specific calibration in areas with high dynamic soil moisture. Besides their purpose of distributing energy, high voltage power lines can also transfer electric signals for measuring and monitoring purposes or for internal telephony of the electric power company. The quality of the signals depends, among others, considerably on the conditions of the surface below the power line, e.g. on soil moisture, snow-cover or canopy. These factors influence the dielectric properties of the surface, can have considerable effects such as spark-over, fluctuations in field strength and additional blind-components on the current transportation, and can cause considerable economic problems for electric power companies. On the other hand, measuring the transfer conditions of high frequency signals such as phase shift and attenuation on longer intersects of power lines can provide information on the situation of the surface below. Due to the high local density of power transmission lines, it would thus in principle be possible to monitor the soil moisture over very large areas and collect data with high economic relevance.

For the purpose of integrated measurements over typically several kilometres, the new "Free-Line-Sensor" has been developed and intensively tested (Königer et al. 2006). The new method is based on the principle that each freely suspended metallic line acts as an antenna for guiding and radiating of electromagnetic waves and can be used as a probe for non-destructive soil moisture sensing. Increasing moisture in the soil raises the DC and the EC of the mixture considerably. This affects the propagation, i.e. the speed and the phase relation, of the electromagnetic waves and influences the signals on the power lines. Alterations of the amplitude and phase of the excited signals need to be recorded with a suitable measuring system. The electromagnetic field of an additional RF-signal in the range of 50 kHz up to 500 kHz on the line is influenced by these changes e.g. after rainfall. The resulting signal is evaluated with respect to amplitude and phase. Comparison with data from gravimetric drying of soil samples shows a good agreement.

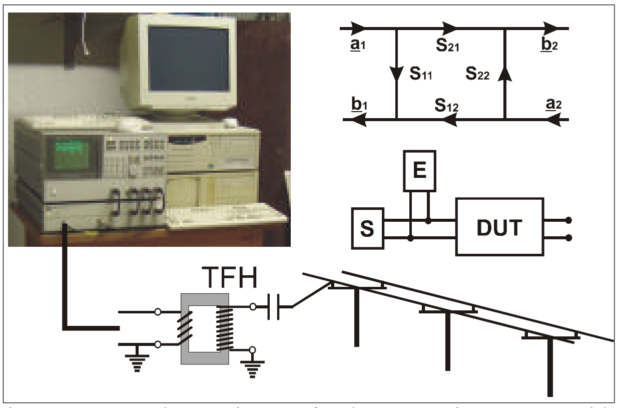

Figure 8: Measuring equipment for the 'Free-Line-Sensor' with vector-network-analyser HP3588B, S-parameter test set HP35677A and personal computer. The meaning of the S-parameters is shown on the right side; measuring parameter is the input reflection factor $S_{11} = \underline{b}_1 / \underline{a}_1$

Figure 9: Signal coupling of the low voltage signal to the high voltage power line using a capacity post of the TFH-equipment

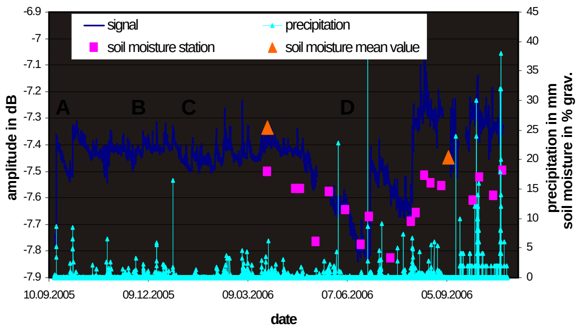

Figure 10: Results of the measured signal, precipitation and soil moisture.

8.2 Ice Load Sensor

Figure 11: A pylon of a power line close to its break down in Winter 05/06 in the NW of Germany [www.wdr.de, accessed on 4.4.08]

As a new setup of the Feeline Sensor is the project "Ice load Sensor" which aims to detect ice covering of the power lines during winter. Such ice load can become very heavy and cause damages on the cables and also on the pylons. In Winter 2005-2006, heavy snowfalls with icing on the cables resulted in a several days longing loss of power in north west of Germany. A powerline crossing the black forest in the southwest of Germany was selected as a test-bed where icing is regularly expected. This project is perfectly designed to combine the benefits of the Free-Line-Sensor with aerial ThIR observations to calibrate the collected signals.

9. OUTLOOK

We believe that ThIR is not that much integrated into the technical monitoring as it should be. Indeed, the relatively poor resolution hampers the coverage of big areas.

Therefore, we work on the improvement of an automated workflow using the combination of photogrammetric aerial survey for applying then the orientation of the aerial images to the ThIR Data. The calibration of the ThIR camera is a difficult task since to use geometrically correct measured Peltier-elements in a calibration test-site has to be done. This delivers the parameters for internal orientation. ThIR Sensors also have to be calibrated for their radiometry, some sensors are pre-calibrated by factory defaults and others only output raw data.

For the mission the use of the AeroStab-3 twin stabilized platform is foreseen. This stabilizer compensates the rotations of the aircraft to less than 0.5 degree and the projection centres measured by GPS results in 1 m accuracy. This stabilizer is able to carry both, aerial camera and ThIR Camera in one. This can assist in running a pre-adjustment to be refined by tie-points in a bundle block adjustment.

A challenge is the use of Ground control points. In some of the applications before, ice-accumulators did a good job as "cold" pass-points. They must be placed shortly before the mission and have to be measured for their coordinates perhaps after then.

Beside aircrafts and helicopters, UAVs might be a suitable platform to carry the ThIR Camera to the air. Newer ThIR Cameras are smaller and can be carried more easily.

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