Advances in Aerial IR Applications

Gregory R. Stockton
AITscan, a division of Stockton Infrared Thermographic Services, Inc.

ABSTRACT
Wide areas and large objects are often most efficiently and effectively infrared (IR) imaged from high above. The main challenge of aerial IR is to maintain the spatial resolution and thermal sensitivity needed to see the slight nuances of temperature differences and trace patterns of heat needed to make accurate judgments about the condition of objects on the ground. There are two types of aerial applications; those where a straight-down view and/or a large area view is needed and those where long distances and/or wide areas must be covered in a limited amount of time. The appropriate selection of the aircraft, aircrew, navigational aids, avionics, infrared imaging systems, analog and digital data acquisition systems and image processing systems are all-important for successful surveying. This paper explores these considerations, along with an assessment of some typical and non-typical applications and methodologies.

INTRODUCTION

The imagery from aerial infrared thermographic surveys of facilities, complexes, campuses and cities can be used for many purposes. Even though most aerial infrared (IR) thermography is performed by military personnel, there are commercial uses. Roof, steam, hot water, chilled water, supply water, storm water and other systems can be imaged from the air, and this information can be used in asset management planning and predictive maintenance (PdM).

The methodology for taking aerial infrared thermographs is similar in many ways to taking aerial visible photographs. To collect the data, the aircraft flies over a given area with an infrared imager looking straight-down (NADIR) or oblique to the ground. The imagery data is then stored on a computer hard drive and later post-processed to produce a report. Where aerial infrared thermography differs from aerial visible photography is in the time of day when the survey occurs and the wavelength of the imagery that the detector collects. IR thermography of ground objects is almost always performed at night. Thermography reveals sources of heat and the relative differences in heat between one object to another.

PLATFORM, EQUIPMENT AND AIRCREW

It is important to collect and process aerial infrared imagery data in an efficient and effective way. Because it is a relatively expensive operation, the job must be done correctly and safely, on the first try. In order to get professional results, equipment that is specifically designed for the task must be utilized.

What is possible and what is not

Using a non-mounted hand-held imager outside an aircraft to survey a small building, a few thousand feet of underground lines or a couple of acres (see Figure 1a) can be completed by flying over and locating the target(s). It is important to locate the targets within in the imagery, save the data, post-process the image and put it into an appropriate report. This works for small areas or low-resolution applications, but it is not possible to make accurate temperature measurements (see Figure 1b).

As with the majority of applications for infrared thermography, most applications for aerial IR are qualitative. However, there are times when the end user wants quantitative measurements. Unfortunately, the infrared cameras that are in general commercial use today cannot measure accurate temperatures on small spots from distances of 50 feet, much less from reliably safe flying distances of 500-1,000 feet and higher. Minimum resolvable temperature difference (MRTD) is a measure for assessing performance. For instance, a one-inch target is not measurable from 500 feet, although it may be detectable. The spot size is on any target that does not have a large homogeneous heat signature is unmanageable and inaccurate. The ground resolution element (GRE) defines the area represented on the ground by one pixel of the sensor. Most IR imagers have about 50% response at one GRE. For close to 100% response, which is needed for temperature measurement, the area on the ground is typically 3X3 GREs. Another way to look at this is a single pixel in the IR camera is sensing energy from an area on the target equal to about 3X3 projected pixels. The bottom line is that one can *detect* a target substantially smaller than one can accurately *measure* it. This shortcoming may be addressed by using more powerful lenses to reduce the GRE for a given distance, but then the sensor's field of view is reduced, limiting the area covered on the ground. In the air, there are few substitutes for a large pixel array.

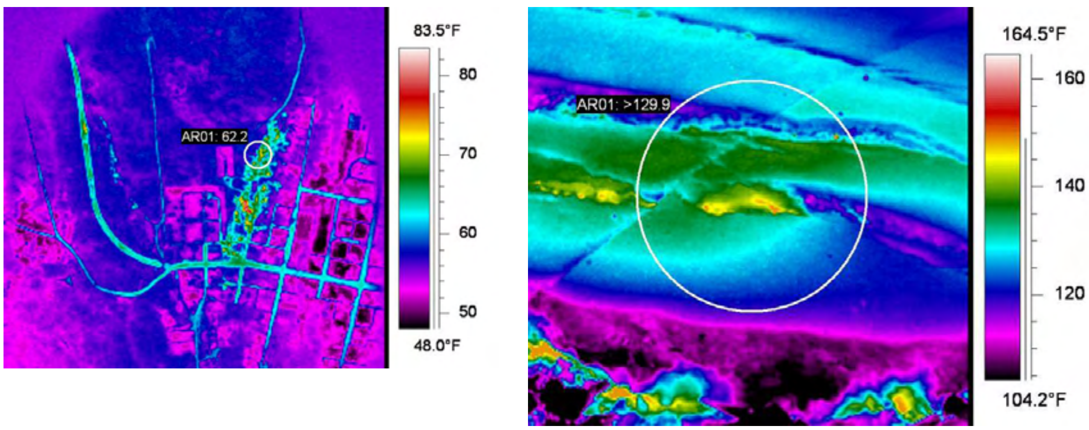

Figure 1.

Aircraft and Infrared Imager

Both helicopters and light airplanes are used to perform aerial IR surveys. Helicopters are best used if the number of targets or distance between targets is low because there are inherent problems with vibrations, slow ferry speeds and high operating costs associated with their use. But helicopters are more maneuverable and can operate at lower altitudes, allowing for the use of lower resolution imagers. Airplanes are used to perform wide-area thermal mapping. The infrared imager must have higher spatial resolution because it must operate at higher altitudes and therefore farther away from the targets. The imager should be fixed-mounted solid, fixed-manually articulated or turret-mounted. In any case, a well-maintained aircraft, experienced aircrew and an imager capable of the resolution required for the intended task must be utilized. The type of infrared imager used will dictate how images are recorded and saved. All controls must be within easy reach and all equipment in the aircraft and must be secured with wires labeled and shielded from electromagnetic interference. Precise navigation is important in any aircraft, particularly so in nighttime aerial infrared operations. Most aerial infrared imaging is performed at night because reflected and direct daylight solar radiation usually adversely affects the imagery and can actually damage the imager.

Aircrew

Flying low and slow and maneuvering without much room for recovery in the dark makes nighttime aerial infrared imaging a job for professional pilots who are specifically trained and experienced in this particular type of flying. The thermographer must be familiar with atmospheric and ground weather conditions, how they will affect the ground target(s) and the techniques for obtaining the desired results. He or she must also know how to operate all the thermographic imaging and data collection systems, and not be prone to airsickness.

Data Collecting and Post-Processing Equipment

Using a low resolution thermal imager that is not fixed-mounted for a surgical IR survey of a small area, where a detailed report is not necessary, can be successful, but it is impossible to make precise thermal maps of whole complexes, campuses, military bases or cities without compositing multiple images. During the flight, the aircraft flies in straight, smooth lines on a pre-planned grid, allowing overlap and side lap of the imagery. The IR operator manages the sensor data acquisition following a structured checklist for orderly data file management. The smaller the array utilized, the more images (exponentially more) it will take to mosaic the imagery.

In order to produce ortho-rectified thermal maps of large areas, more information must be gathered and tagged to the IR imagery. The imagery must be collected with a precise direct-digital timing system, a 3-axis ring-laser-gyro and an inertial navigation system (INS), which is tightly coupled to a real-time differential GPS satellite positioning system that provides x, y, z positioning of the sensor at all times (see Figures 2). After data is collected, the digital infrared imagery is processed into a series of ortho-rectified image tiles, which are then stitched together to create a mosaic thermal image (see Figure 3a) to match the visible image (see Figure 3b). A computer system puts all this information together using a digital elevation model (DEM) of the scene that consists of a uniform grid of point elevation values and the position and orientation of the camera with respect to a three-dimensional coordinate system output. The result is presented as a high-resolution thermal image in the form of a geo-TIFF, which is compatible with any GIS or CAD software.

Once high quality digital thermal and photographic ortho-rectified maps are created, they can be added as layers to other data sets, to existing or new CAD and GIS systems. Digital data can also be post-processed in other ways, such as creating false color imagery to highlight areas of interest, adding temperature data and/or creating graphic reports.

Figure 2. High resolution aerial IR imaging, data collection system, and aircraft.

AERIAL IR APPLICATIONS

When an object on the ground (or in the ground) is producing heat, surface temperatures may be affected. When an object is heated or cooled, differences in the mass of the object can be observed thermally. During the day, the sun heats objects directly by radiation and indirectly by raising the ambient temperature. Then at night these objects cool at different rates according to their thermal mass and other properties. It is possible to make judgments about these objects based on their thermal characteristics. There are many applications for aerial IR imagery, and examples are below.

Steam distribution systems
Aerial infrared can help asset managers monitor steam distribution and condensate return systems. Thermal contrast between active lines and the surrounding ground is usually good, depending on the depth of the line, temperature, flow and the properties of the materials covering the lines. The entire system can be flown, a mosaic thermal image produced, and the areas with suspected problems pinpointed, documented and scheduled for repair.

Steam and condensate return lines are usually readily visible with aerial infrared imaging, even when no notable problems exist. This is due to the fact that no matter how good the insulation, there is usually some heat loss from the lines that makes its way to the ground surface. Problem areas are generally quite evident, having brighter infrared signatures that the norm.

Figure 3a. Infrared mosaic of a small university campus with grid lines overlaid.

Figure 3b. Visible mosaic of a small university campus with grid lines overlaid.

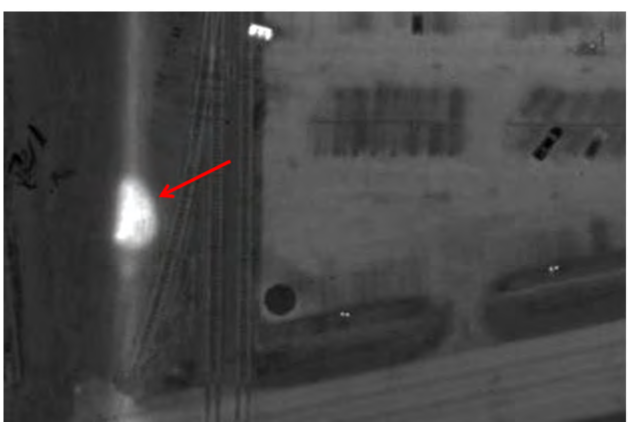

Figure 4a. Infrared image of a steam leak in a steam distribution line.

Figure 4b. Infrared image of a steam distribution line leaking liquid up, onto the ground surface.

Steam line faults normally appear as an overheated line or as a large hotspot in the form of a bulge or balloon along the line (see Figures 4). If a steam line is buried directly in the ground with an insulating jacket, a leak will usually saturate the insulation, rendering it largely ineffective. It will begin to transfer heat into the ground around the leak. Overheated lines often occur when the steam line is located in a conduit or tunnel. If there is a leak in the line, it will heat up the conduit with escaping steam. Manholes or vaults that contain leaking steam system control apparatus, will often heat the covers to warmer than normal temperatures. Unless these leaks are severe enough to significantly raise the manhole temperature above their normally elevated temperatures, these leaks can be difficult to identify.

Steam line infrared imagery can be a little misleading, unless one understands and interprets the relative brightness and temperature of a given line correctly. For instance, a steam line that is the same temperature from one end to the other and passes under different surfaces and materials can exhibit a variety of real and perceived temperature variations. Five different apparent temperatures will result from the same temperature line that runs under a grass-covered field, an asphalt roadway, a concrete loading dock, a gravel-covered parking lot and a bare earth pathway.

Other district heating and cooling systems
High temperature hot water (HTHW), medium temperature hot water (MTHW) and low temperature hot water (LTHW) lines are similar to steam distribution and condensate return systems, with an associated graduated degree of difficulty in surveying, because of the declining temperature difference between the line and the surface. Chilled water supply (CHWS) and chilled water return (CHWR) lines are usually cooler than the surface temperature and can be surveyed for thermal loss and leaks (see Figure 5).

Figure 5. Buried chilled water line cools the surface above the line.

Figure 6. IR Imagery of a storm water drainage system outfall flowing into a creek.

High voltage electric utility transmission lines
Detecting electrical faults on high voltage electrical transmission lines is fairly easy and can be accomplished rapidly from a light aircraft or helicopter. Typical problems are loose and/or deteriorated connections. Qualitative data is relatively easy to collect, but, as discussed above, a problem on a small target (like high voltage transmission line splice) taken from a moving, vibrating aircraft may be *detected*, but cannot be *measured* from safe flying distances. So when these anomalies are found, they must be

compared to similarly loaded phases or equipment, then identified, saved and marked on a map. If more accurate measurements are needed, a ground verification team can be used to inspect suspicious hot spots from the ground and quantify the findings of the aerial IR survey. They will be closer to the target, and with a powerful lens on a stable surface, much more accurate. Because they are smaller, lower to the ground and often run through populated areas with much thermal clutter, high voltage electrical distribution lines are much more difficult to survey from the air and are best left to ground-based thermographers.

Waterways

Storm water collection systems are engineered to discharge into surface waters and to efficiently drain rain water from a given area. But all too often, these systems convey pollutants from illicit connections, degraded sanitary sewers and other sources. Locating these point sources on the ground is a labor-intensive task, often relying on sampling data from sites that may be blocks or even miles from the actual source.

Liquids flowing into the body of most waterways can be identified using aerial infrared (see Figure 6), as long as there is a temperature difference between the two liquids. These dry weather flows are heated by having been underground at some point and can be detected where they join the water in a creek, stream, river, lake or ocean during cooler times of the year. Leaks from nearby water, sewer and/or storm water lines and direct run-off from a sloped surface can be detected because they produce a warm flow over the ground toward the water and a warm plume joining and flowing downstream with the main body of water.

Waterways are best surveyed during times of the year when the ambient temperature at night is well below (a ∆T of ~15C degrees) the temperature of the ground temperature (1-2 meters deep) and overhanging foliage is minimized. Aerial infrared surveys can help waterway managers identify, quantify, document and remove previously unidentified discharges. Aerial infrared surveying can also to track pollution such as waste or oil spills and monitor sewage treatment plant discharges, manage heated water from power plant cooling lakes (see Figure 7), monitor ground water seepage into rivers, streams and lakes and measure the amount of fresh water from ground sources introduced into an estuary.

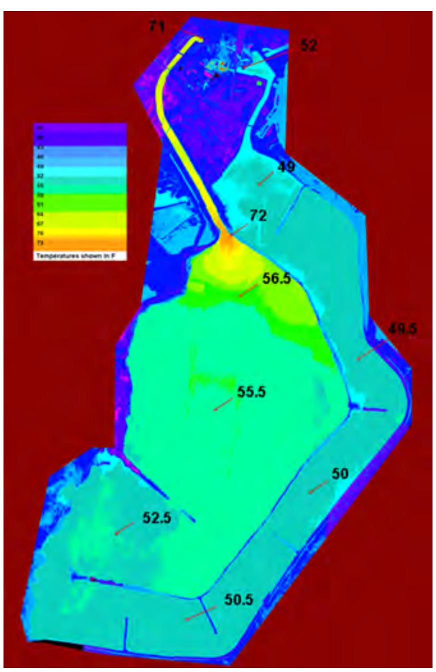

Figure 7. IR imagery of a power plant's cooling lake.

Geothermal IR imaging
When a road or building complex is planned, the site can be surveyed with aerial IR to determine if any geothermal activity is present at the surface. This will allow the planner to route the road around the activity or decide the site is unsuitable for the intended purpose.

Structural fires
Aerial infrared can be helpful to the firefighters of structural fires. Often the smoke escapes the building from a location other than the hottest part of the fire. These areas can be imaged and the firefighters informed as to the location of the hot spots.

Forest fires
Aerial infrared imaging can be used to monitor and manage forest fires. By creating accurate mosaic thermal maps (see Figure 8), fire management and suppression efforts can be adjusted for active fires. This information can be sent immediately to those in charge of controlling fire lines. Thermal intensity is resolved to classify the hottest sections of the active fire, therefore pinpointing the areas of most intense thermal energy. These digital aerial maps are loaded to hand held GPS devices to enable ground teams to navigate directly to the hotspots most rapidly by either walking, driving or flying to them in a helicopter. Thermal IR provides an important visual reference locator by identifying the hot spots with respect to terrain features in the thermal imagery. Positive identification of hotspots is accurate and rapid even through dense smoke.

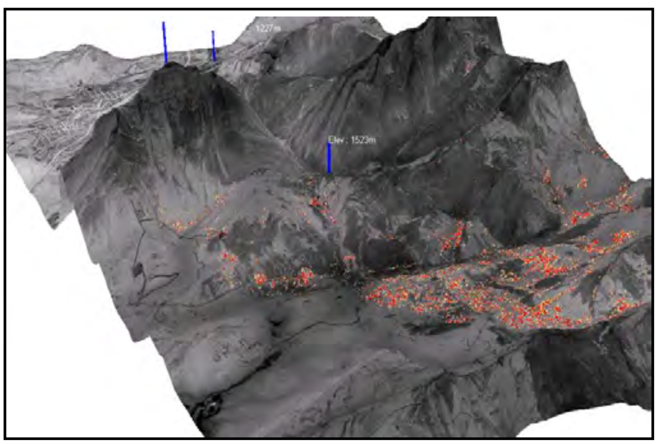

Figure 8. 1000-IR image fire mosaic draped on 3D terrain model.

Figure 9. IR imagery of a subsurface fire in landfill.

Other surface and subsurface fires
Landfill fires (see Figure 9) can be hazardous to the surrounding environment. Knowing where, how many and the extent of these underground fires is useful information for those in charge of containing or extinguishing them. Similarly, peat, coal and wood chip piles, which combust spontaneously, can be monitored.

Aerial infrared roof moisture surveys
Building roofs are an expensive and onerous asset to maintain. Roof moisture surveying is an example of the exceptional efficiency and effectiveness of using high resolution aerial infrared imaging to provide condition monitoring. Drawing the entrained moisture in flat and low-sloped roofs on a CAD drawing with surgical precision (see Figure 10) provides a significant PdM benefit to the building asset manager. Entrained moisture in the insulation and other roof substrates is indicative of leaks in the waterproofing,

seams and flashings. Regular aerial infrared surveys help the owner assess the condition of the building roof based on unbiased hard data, by quantifying areas of moisture contamination in the roof.

Areas of roof moisture contamination often manifest themselves as warmer areas that may be nebulous in shape and sometimes mottled in appearance, although they are commonly found in linear or puddle-like shapes. Many times the linear shapes follow low areas, drainage routes, roof edges and seams. Puddle-like round or oblong shapes often form around roof penetrations such as mechanical equipment, standpipes, vents and drains. The wet areas are warmer because the latent heat (from daylight sunshine) in the trapped water mass is greater than in the dry, functioning insulation or roof substrate. After sunset when the roof structure cools down, wet areas of roof insulation and other materials continue to radiate heat, allowing infrared cameras to detect the sources of heat and record them for later analysis.

Straight-down aerial imagery shows large damp areas to be detected in one image. This allows for the slightest temperature differences to be noted. High resolution aerial imagery captures large areas, while lessening reflection problems, eliminating perspective problems and all of on-roof infrared's other physical and logistical problems, such as access to multiple levels, security and nighttime safety issues. Aerial thermographers can survey many roofs at a time while conditions are good and analyze the data later in an office setting. Plan view imaging allows for the precise, accurate marking of areas of suspect roof moisture contamination. Infrared images, visual images and CAD drawings (see Figures 11) can be reconciled closely, making the reports accurate, clear, concise and easy to understand. Surgical removal of wet insulation and repairs can be completed and trending becomes possible.

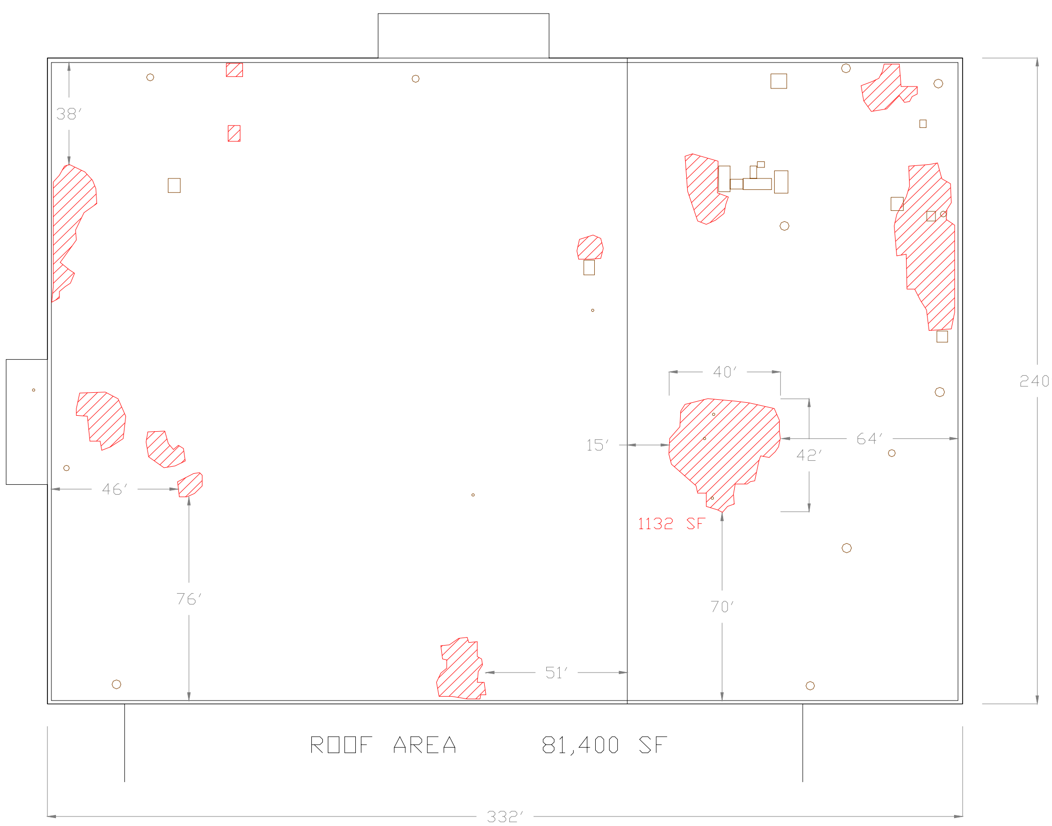

Figure 10. CAD drawing with areas of subsurface moisture defined and quantified.

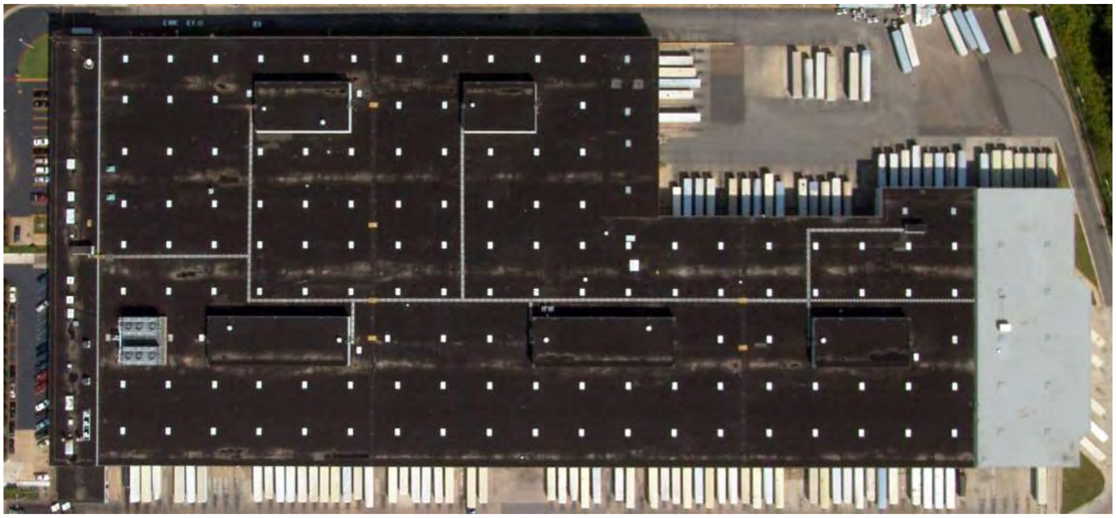

Figure 11a. Photographic image of a large warehouse.

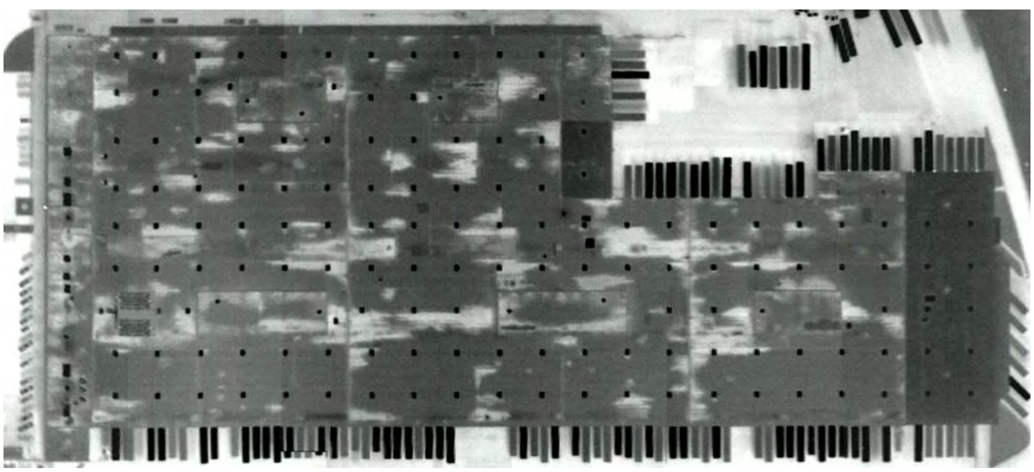

Figure 11b. Thermograph of a large warehouse.

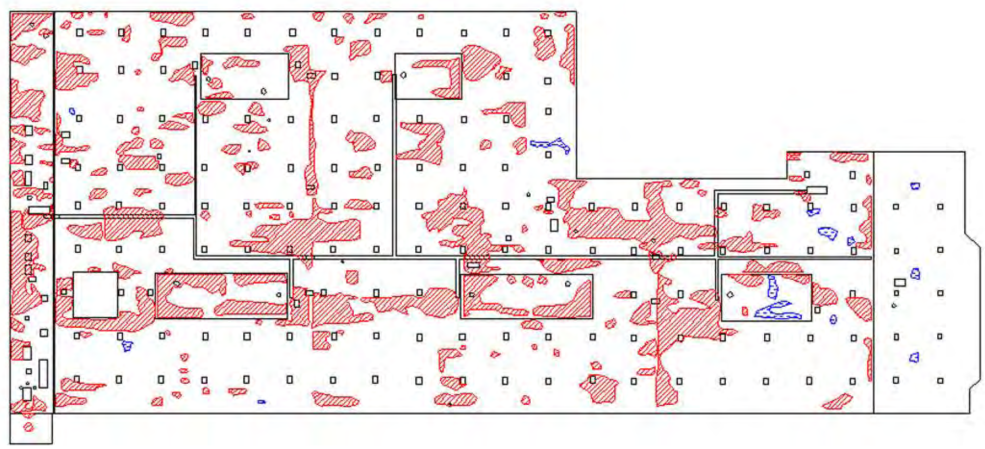

Figure 11c. CAD drawing with areas of subsurface moisture defined in red.

The most cost-effective roof condition monitoring method

A thermal and visual map of a campus can be used for many purposes, as shown above. These images can be added to existing CAD or GIS data sets as layers or stand-alone. One giant thermal mosaic image and one giant photo mosaic image can be used to find out *which* roofs need an IR roof moisture survey, therefore the owner of many building roofs on a campus need not pay for thermographic surveys for all the roofs.

The mosaic images and digital data can be reviewed, revealing the condition of many systems, including those of the roofs. Some roofs are going to be dry and for trending purposes, the mosaics will work perfectly at no additional cost to the owner. Because of roof thermal dynamics and physics, some types of roofs cannot be successfully surveyed with infrared at all. Often the details of the roof type and history of every roof are not available. Why would the manager want to pay for all those roofs that cannot be successfully IR surveyed? The best way is to create these giant images and use them to prepare a list of all the roofs that need an analysis, naming any roofs that have entrained moisture. These roofs can then be post-processed at a minimal cost to produce individual roof condition reports, since the image data has already been saved from the flight.

The marketing and sales departments of roofing companies, roof consultants and roof manufacturers can greatly benefit from IR and visible imagery of large areas with high concentrations of flat and low-sloped roofs. They can use even low resolution imagery to determine which roofs have subsurface problems and target their sales and marketing efforts to owners of those buildings.

What does not Work

Unfortunately, 'wholesale' building heat loss surveys cannot be accomplished with a NADIR thermal survey, primarily because most building roofs are decoupled from the heat loss of the building, either with ventilation, with insulation or by being so reflective that they are immeasurable with IR sensors. Oblique aerial or on-ground, right-angle infrared surveying of the walls will be necessary to accomplish building heat loss surveys.

SUMMARY

The imagery from aerial infrared thermographic surveys of facilities, complexes, campuses and cities is useful for many purposes. Wide areas and large objects are most effectively imaged from the air, as long as thermal sensitivity and spatial resolution are maintained. As the hardware and software improve and become less expensive, larger areas will be able to be imaged at an ever-decreasing cost per acre.

AUTHOR BIOGRAPHY

Gregory R. Stockton is president of Stockton Infrared Thermographic Services, Inc. Based in Randleman, NC; the corporation operates four application-specific divisions. Greg has been a practicing infrared thermographer since 1989. He is a certified infrared thermographer with twenty-six years experience in the construction industry, specializing in maintenance and energy-related technologies. Mr. Stockton has published twelve technical papers on the subject of infrared thermography and written numerous articles about applications for infrared thermography in trade publications and magazines. He is a member of the Program Committee of SPIE (Society of Photo-Optical Instrumentation Engineers) Thermosense and Chairman of the Buildings & Infrastructures Session at the Defense & Security Symposium.

Understanding IR Imagery

Infrared imagery is a grayscale picture whose scales (or shades of gray) represent the differences in temperature and emissivity of objects in the image. Typically, objects in the image that look lighter are warmer, and those that look darker are cooler…bright white objects being the warmest and black objects, the coolest.

Any object with a temperature above absolute zero (0 Kelvin or –273 degrees Celsius) emits infrared radiation. An infrared picture only shows objects which emit infrared wavelengths in the 3000-5000 nanometer (mid-wave) range or 8000-14000 (long-wave) range. Objects in visible light wavelengths of 400 to 700 nanometers are detected, but only because they also emit heat. An example of this would be a street light that can be seen in the IR imagery because the ballast and bulb are warm.

Infrared imagery is usually recorded on digital media and later copied to a deliverable such as a DVD-Video, videotape and/or captured as digital image files. The images may then be modified in a number of ways to enhance their value to the end-user, such as creating false-color imagery and/or adjusting the brightness and contrast of a grayscale image to be used in a condition report.