# Advances in Applications and Methodology for Aerial Infrared Thermography

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## ABSTRACT

Most aerial infrared (IR) is performed by the military, but there are commercial uses. Some of these non-military applications are the focus of this paper. Generally speaking, the farther away one can get from the object of an infrared survey, while maintaining the needed spatial resolution and thermal sensitivity, the more usable the data is. Wide areas and large objects can be effectively imaged from the air. In fact, the use of high-resolution aerial infrared imagery is often the only way that one can see slight nuances of temperature differences and trace the patterns of heat. In order to produce an easy to understand, high quality and useable report, the data must be acquired, recorded and processed in an efficient and effective way. This paper discusses the ongoing advances in methodology, platform and equipment required to produce high quality usable data for the end-user.

**Keywords:** Aerial, infrared (IR), thermography, global positioning system (GPS), video encoder-decoder (VED), computer aided design & drafting (CADD), pollution, stormwater, high voltage electrical transmission lines, high voltage electrical distribution lines, steam system, high temperature hot water system (HTHW), forest fires, subsurface fires, landfill fires, peat, coal and wood chip piles, structural fires, animal census, search and rescue (SAR), roof moisture surveys, geothermal, pipelines.

## 1. INTRODUCTION

Aerial infrared applications can be divided into two categories; those where a straight-down view and/or a large area view is needed and those where long distances must be covered in a limited amount of time. Selection of aircraft, aircrew, navigational aids, infrared imaging system, data acquisition and image processing system are all important to a successful survey.

## 2. EQUIPMENT, CREW AND DATA PROCESSING

In order to get professional results, equipment that is specifically designed for the task must be utilized. Because it is a relatively expensive operation, the job must be done right [and safely] the first time. Both helicopters and light airplanes can be used to perform aerial infrared surveys. Helicopters are best used if the number of targets or distance between targets is low because there are inherent problems with vibrations, slower ferry speeds and higher operating costs. These problems can be offset by being able to use relatively inexpensive smaller format imagers. If a light airplane is used, the imager must have higher spatial resolution (~262,000 pixels or more) because it must operate at higher altitudes and therefore farther away from the target, allowing at least the same resolution from as much as four times the distance. The advantage of using a large format imager is that the field of view (FOV) is larger, making report preparation much easier and the report product superior. Larger lenses can improve the needed ground resolution element (GRE) or the size of one pixel on the ground, if some signal strength degradation is acceptable, but the FOV suffers as a result. One might mosaic or ‘paste’ many images together but this is very labor-intensive and can often result in a greatly distorted and unmanageable (extremely large) image. More pixels are always better. Our research and experience in many different aerial infrared applications has shown that a hand held, small format imager held out the open window of a helicopter will definitely not produce professional results. The imager must be fixed mounted solid (See Figure 1), 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 should be utilized.

Figure 1. Photograph of a large format infrared imager, fixed-mounted in a light aircraft.

The type of infrared imager used will dictate how images are recorded and saved. Modern infrared cameras have a wide variety of storage media. The pilot and thermographer are extremely busy during the flight, so every possible anomaly will not be seen while in the air. No matter what type of imager or storage medium, a digital videotaped record of all the ‘raw’ infrared imaging should always be made. Controls must be within easy reach and all equipment in the aircraft must be secured with wires labeled, shielded from electromagnetic interference and out of the way.

Precise navigation is important in any aircraft and particularly so in nighttime aerial infrared operations. A global positioning system (GPS) is a necessity. A GPS with a mobile mapping program on a computer and a video encoder-decoder (VED) is very useful, especially when multiple targets need to be imaged. The VED encodes the videotape with a continuous stream of GPS derived data (latitude/longitude, altitude, date, time and speed, etc.) and displays the information through the video signal (See Figure 2). Most aerial infrared imaging is performed at night because reflected and direct daylight solar radiation usually adversely affects the imagery and can damage the imagers. Flying low and slow and maneuvering without much room for recovery in the dark makes nighttime aerial infrared imaging a job for professional pilots specifically trained and experienced in this particular type of work.

The office equipment needed to analyze imagery and produce aerial infrared reports is similar to that used by ground-based thermographers. This equipment includes powerful computer workstations with digital photographic and thermographic imaging peripherals, digital video capture systems, image processing hardware and a photographic-quality printer. Software includes computer aided design & drafting (CADD) software, mapping software and other programs capable of producing specialized parts of the final report product in a popular format.

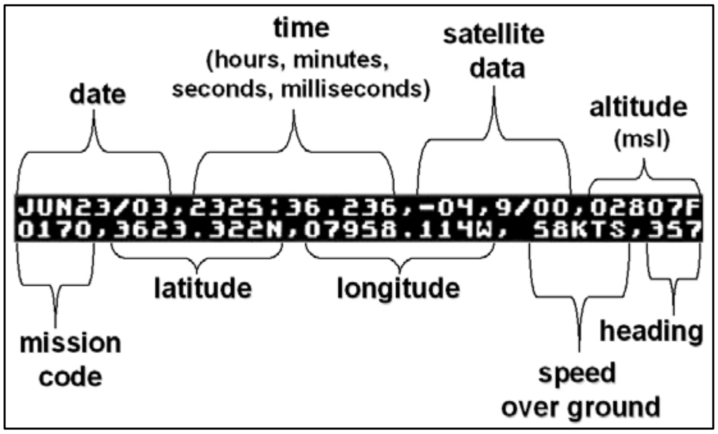


Figure 2. Annotated guide for a video encoder-decoder (VED).

## 3. APPLICATIONS

### 3.1 Waterways

Liquids flowing into the body of other liquids can be identified using infrared thermography if there is a temperature difference between the two. Typically, polluted water is heated by being underground at some point and can be detected by using aerial infrared thermography when it joins the water in a creek, stream, river or lake during cooler times of the year. Leaks from nearby water, sewer and/or stormwater lines and direct run-off from a sloped surface can be detected because the warm plume flowing over the ground toward the water and the liquid joining and flowing downstream with the main body of water are visible in the thermal infrared spectrum (See Figure 3).


Figure 3. Thermograph of a stormwater drainage system outfall flowing into a creek.

In most parts of the United States, for instance, late fall, winter and early spring are well suited to this type of inspection because the difference between water temperatures (ground and surface waters) is present and because interference to view due to overhanging foliage is minimized. Aerial infrared thermographic surveys can help municipalities identify, quantify, document and remove previously unidentified stream discharges. Stormwater collection systems are engineered to discharge into surface waters to efficiently drain selected areas. 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. An aerial infrared survey of these waterways will find these point sources, allowing municipalities to prioritize areas of concern and concentrate efforts and scarce resources on these locations first. The waterway is flown and infrared images are saved with exact location information of each thermal anomaly. A map is then created with exact latitude/longitude of each marked area. The end-user/system operator then takes a hand held GPS device to each location and tests the outfall for signs of contamination. Aerial IR can also be used to track pollution such as waste spills or oil spills, monitor sewage treatment plant discharges, manage heated water from power plant cooling towers, monitor ground water seepage into rivers, streams and lakes and measure the amount of fresh water from ground sources that are introduced into an estuary.

### 3.2 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. But even from short distances, accurate temperatures of electrical faults are impossible to measure. There are several problems associated with temperature measurement from the air which include spot size to target distance ratios, reflection of the objects surveyed, having a sufficient load on the line at the time of the survey among others. The spot size to target distance ratio is the biggest problem with temperature measurement. Specification writers have not yet realized the seriousness of this problem and continue to ask for quantitative data on fault areas. The fact is that infrared cameras that are in general commercial use today cannot measure accurate temperatures on small objects from distances of 50 feet...much less from reliably safe flying distances in a moving aircraft. A one-inch (relative size of a transmission line splice) target cannot be *measured* from that distance, plain and simple, although it can be *detected*. These spot sizes are unmanageable and inaccurate on any target that does not have a large homogeneous heat signature. The GRE is critical to the measure of spatial resolution in aerial infrared thermography. Nyquist's frequency theorem states that an object less than two times the size of a sensor's GRE cannot be resolved for measurement, so a 3x3 pixel or GRE spot is needed for reliably obtaining measurements.

This shortcoming may be addressed by using more powerful lens to reduce the GRE for a given distance, but then the sensor's FOV is then reduced, limiting the area covered over a given period of time. So, if one is using a small format IR camera (256x256 pixels) in a helicopter only 50 feet away from a 1 inch “hot spot”, it is impossible to obtain accurate temperatures using a standard lens. The smallest “hot spot” that could be accurately measured with one of these imagers is over 2", even at that extreme short distance. Also, from the air, using a more powerful lens does not work well because vibration is more evident in the form of image 'shaking'. Image 'smearing' may also occur due to an increase in the apparent speed of the sensor's view across the ground. In the air, there are few substitutes for a large pixel array, but even using large format detectors, one cannot and should not profess to *measure* temperatures on very small objects. These anomalies can be seen, and by comparing them to similarly loaded phases or equipment, potential problem areas can be identified, saved and marked on a map. For ‘good’ measurements, a ground verification team should be used to inspect suspect hot spots from the ground (cloudy nights are best) and verify 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, high voltage electrical distribution lines are much more difficult to see against all the thermal clutter on the ground such as trees, street lights, people, animals, etc., than transmission lines. Therefore, distribution lines are best left to be inspected by ground-based thermographers.

### 3.3 Steam and High Temperature Hot Water (HTHW) Systems

Checking the boilers and the lines in steam plants and tunnels are jobs done on the ground, but the distribution and condensate return lines that are direct-buried are best surveyed from the air. In fact, even from high altitudes, steam line inspections are one of the easiest applications for aerial infrared thermographers. Thermal contrast between active steam lines and the surrounding ground are usually good. The entire system can be flown and areas with problems pinpointed and documented. A key-word searchable database of thermographic, photographic and drawings, along with other data sets can be produced for the system operator. Underground steam lines are almost always readily visible with infrared imaging, even when no notable problems exist. This is due to the fact that no matter how good the insulation, there is always heat loss from the lines which makes its way to the surface. Problem areas are generally quite evident, having brighter white IR signatures that exceed the norm. Steam line leaks (See Figure 4) normally appear as an overheated line or as a large hotspot in the form of a bulge or balloon along the line. 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 whole conduit with escaping steam. 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 and will begin to transfer heat into the ground around the leak, producing the classic bulge or balloon-like hot area straddling the line. Finally, some leaks may show up as an overheated manhole or vault cover. Manholes or vaults that contain steam system control apparatus which are leaking, will often heat the iron covers to warmer than normal temperatures. Unless these leaks are severe enough to significantly raise the manhole temperature above their normally slightly elevated temperatures they can be difficult to identify. At times, steam line imagery can be a little misleading to analyze unless one understands and interprets the relative brightness/temperature of a given line correctly. A steam line that is the same temperature from one end to the other that passes under different surfaces and materials can exhibit a variety of temperature variations. For example, five different apparent temperatures will result from the same temperature line that runs under a grass-covered field, an asphalt parking lot, a concrete loading dock, a gravel-covered area and bare earth pathway. While not as highly contrasted, HTHW loops can be flown in the same manner as steam systems. Occasionally HTHW leaks appear as cool spots because the water has come to the surface and is being cooled by evaporation.


Figure 4. Thermograph of an underground steam system leak.

**3.4 Forest Fires**

The U.S. Forest Service uses aerial infrared imaging to monitor forest fires. Very accurate mosaic infrared maps of active fires can be made to help with fire management and suppression efforts. 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 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 rapid even through dense smoke.

### 3.5 Subsurface Fires

Landfill fires (See Figure 5) can be hazardous to the surrounding environment. Knowing where, how many and the extent of these fires underground is useful information to those in charge of containing or extinguishing them. Similarly, peat, coal and wood chip piles, which combust spontaneously, can be monitored.


Figure 5. Thermograph of a subsurface landfill fire.

### 3.6 Structural Fires

Aerial infrared can be helpful to the firefighters of structural fires especially on large, single story buildings. Often the smoke escapes the building from a different location than the hottest part of the fire. These areas can be imaged and the firefighters informed as to the location of the hot spots.

### 3.7 Animal Census

Many warm-blooded animals can be found and counted from the air. Aerial IR is far more accurate than any other method and is primarily used by government agencies. Deer, moose and large migratory birds are among animals most often counted. Population density information is used to monitor and control the population of these animals on city, county, state and federal lands.

### 3.8 Search and Rescue (SAR)

SAR operations are often ‘rush’ jobs where conditions are less than ideal. Aerial infrared SAR is better than ground-based SAR in most instances however it is still very overrated. People targets either do not want to be seen, are disabled and unable to move to an area where they can be seen, or are trying to keep the warmth of their body close by insulating themselves, so they cannot be seen.

### 3.9 Roof Moisture Surveys

Regular aerial infrared surveys of help building owners assess the condition of their building roof based on hard data, by quantifying areas of moisture contamination in insulated flat or low-sloped roofs (See Figures 6, 7, 8).

Figure 6. Photograph of a flat roof.

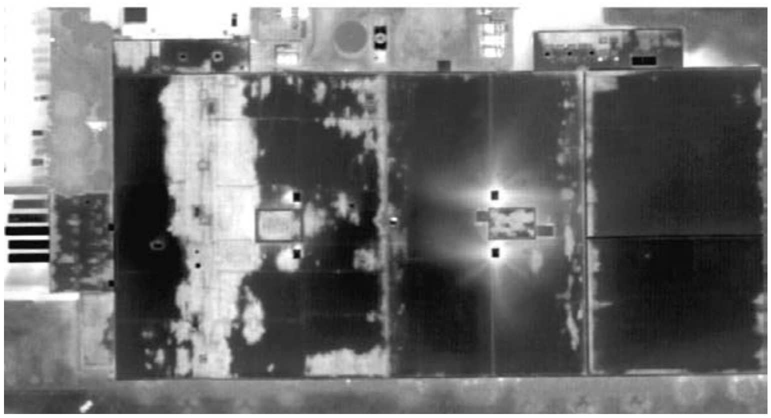

Figure 7. Thermograph of a flat roof.

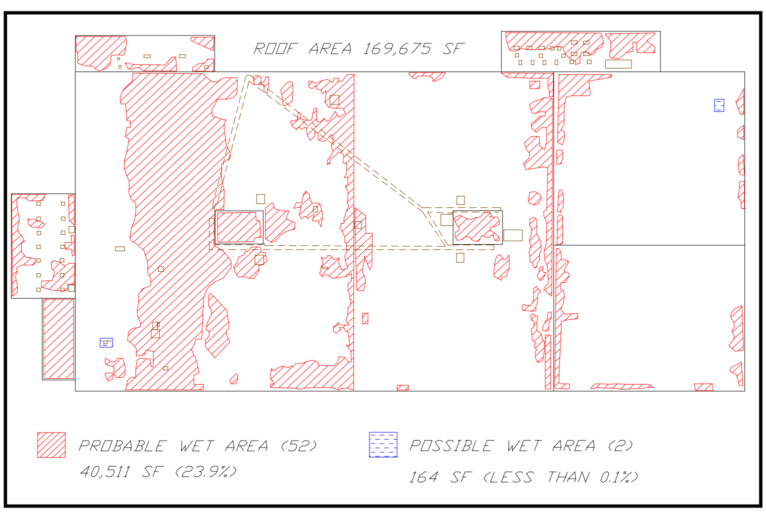


Figure 8. CADD drawing of a flat roof.

Straight down aerial imagery is much more useful to a building owner than on-roof imagery because infrared images are taken 'plan view' and large areas can be seen in one image allowing the slightest temperature differences to be noted. High-resolution aerial imagery captures large areas at once, making the report easier and therefore less expensive to produce, while lessening reflection and perspective problems and eliminating all of on-roof infrared's logistical problems, like man-hours required, access to multiple levels, security and on-roof nighttime safety. Aerial thermographers can survey many roofs in one night while conditions are good and process the data in an office setting, instead of on a roof at night. Plan view imaging allows for the precise, accurate marking of areas of suspect roof moisture contamination. Infrared images, visual images and CADD drawings can be reconciled closely, making the report accurate, clear, concise and easy to understand. Drawings are made by 'overlaying' the photographs and thermographs. Reports include a digital videotape, aerial photographs, printed thermographs, CADD drawings and/or an image database. Surgical removal of wet insulation and repairs can then be accomplished.

### 3.10 Geothermal

When a road or building complex is planned, the site can be flown over 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.

### 3.11 Pipes and Pipelines

Pipes and pipelines are usually difficult to survey. Trees, shrubs, brush, water and man-made structures like bridges, roads, sidewalks and buildings often cover pipes. If a liquid is leaking from a pipe and the location of the leak is unknown, an aerial IR survey can be used to find the leak. Even if the pipe itself cannot be seen on the surface, it may be possible to see the leaking liquid and narrow the search to a relative small area. The best results are found when the pipe is not buried deeply, has a high flow and when the difference in temperature between the liquid in the pipe and the ground above is high. We have flown over known leaks on natural gas pipelines and not been able to detect any temperature difference on the pipe or the sounding surfaces. Usually, color IR (CIR) and *not thermal IR* is more effective. CIR is used to see damage to vegetation around the leak.

## 4. CONCLUSIONS

There are many commercial uses for aerial infrared thermography. The aircraft, imager and crew must be capable of performing the tasks and providing professional results. With improvements in thermographic and photographic equipment, flight methodology and data acquisition systems, aerial infrared thermography will continue to improve in the years ahead.