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Think Thermally®

Practical news for practicing thermographers

In This Issue:

Designing and Constructing Effective Infrared Routes

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The Snell Group

It is widely acknowledged that the most efficient infrared condition monitoring program is one that has a strong foundation of well designed and thoughtfully constructed routes. The key to success in your unique environment is to understand the six generic types of routes used by thermographers and where they can be applied.

Routes by location are probably the most common type as they can help you organize a large complex or multi-unit facilities. Simply define a region, whether a room, floor, or any well defined area and systematically scan all the equipment within those boundaries before continuing on. An example of location based routing might be an electrical substation, pump house or a boiler room.

Routes by process logically follow a process flow, most often from start to finish. The thermographer maintains this contact throughout the entire inspection often finding operational issues as one segment relates and impacts another. A very large or multifaceted process can be divided into smaller more manageable sub-routes yet still follow the process stream. Production lines, steam and condensate systems and overhead bus electrical distribution are good candidates for the process type of route.

Routes by equipment type can be very efficient when a site has multiple pieces of like equipment throughout large areas. As the thermographer is only observing, comparing and analyzing one specific type of equipment repeatedly, he/she gains a heightened sense of awareness of how that equipment should appear. This type of route also lends itself very well to situations where the thermographer must use an unusual procedure or special equipment. Examples of an equipment type route would be resistance welding robots, motors, pumps or rotating groups.

Routes by availability or load are constructed considering which piece of equipment is running during a given period or by load cycle. A great deal of

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John Snell, Principal
The Snell Group

A Simple Mind Contemplates Complexity

My mind wants life to be simple. It can be useful to view the world like this—I often look longer term and worry less about short-term "noise"— but, clearly, much of life is quite complex.

Even after 25 years of looking at buildings with thermography, they continue to humble my reasoning processes because getting at the truth of what is going on is almost always complicated.

I recently completed inspections of two open wall, spray-foam jobs—one residential, the other a commercial renovation—and rejected both due to excessive air leakage that was detected. Buildings insulated like this should not continue to have massive air leakage problems! Only by viewing the buildings under various thermal and pressure scenarios and also by digging deep—and destructively—into the structure, was I able to conclusively determine the root cause of the problems. Buildings are complex and understanding their real world performance is often even more complicated!

Of course we regularly hear tales in our classes about the complexities of evaluating machine asset health. The temperature of a machine can change for many reasons, including because a problem is getting worse. Because of the inherent limitations of basing an analysis only on the temperature of the machine—especially the radiometric temperature—most maintenance professionals also use additional tools in the process of evaluating asset health.

More information is good, but also, potentially, confusing and complex. When we bring together the details of temperature, power quality, motor circuit analysis, lubrication, vibration, ultrasound and dissolved gas, among others, the process of finding a common thread can be very complicated. After solutions have been found, life may seem simple but let's not kid ourselves: keeping our systems of machine assets healthy and available is a complex task requiring a high level of skill and experience!

The Earth is also a complex system, really a system of systems. The "condition monitoring" data we are now seeing suggests changes, mainly thermal, are underway. While the debate over the "root cause" of global warming is still ongoing, few can ignore the effects, many of which appear to be significant. A warm summer or a snowy winter may be minor perturbations but the photographs of glaciers receding over the last century, for example, are real and concerning.

This system we call Earth is complex. Rather than being paralyzed by that fact, however, my simple mind tells me we can use these remarkable technologies we have in hand to begin reducing energy use and improving efficiencies. Just

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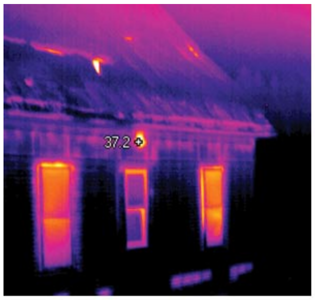
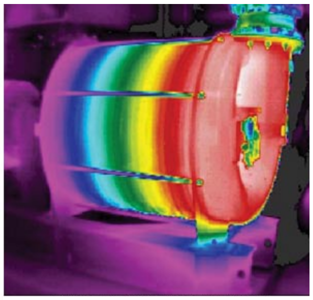


Image courtesy of NASA



Greg McIntosh, P. Eng., Managing Director
Snell Infrared Canada

Measurement Resolution (IFOVm)

I have fielded quite a few questions about my *Think Thermally* article on IFOV from the Fall of 2006 (available online in the Knowledge Center at www.thesnellgroup.com). There still appears to be a lot of confusion about ***measurement resolution*** which I am happy to address. Some typical questions have been:

- If I can detect a hot spot why can't I also measure it accurately?
- If I can detect it why can't I apply a correction factor?
- Isn't that what the distance value in my camera corrects for?

Measurement resolution is the term used to define the spatial measurement capabilities of the camera. Defined as ***"the minimum spatial size for measurement,"*** it is also referred to as Instantaneous Field of View (IFOVm). The value for IFOVm cannot be a set physical size since it will vary with the inspection distance. The greater the distance the larger the IFOVm. It must be expressed as some sort of ratio or diverging angle.

Measurement resolution will define the minimum object size that can be measured with reasonable accuracy using a specific camera and lens combination. It is usually expressed in milliradians (mr) which is the object size that can be measured at 1000 units of distance.

A camera which has a 4 mr measurement resolution means it can measure, with reasonable accuracy, a high emissivity object that is 4 mm in size at 1000mm (or 1m). Measurement resolution is typically defined by one of two methods: 1) a theoretical pixel method which states the minimum number of adjacent pixels that a manufacturer believes produces a reliable measurement and 2) by an actual camera test, called a 95% or 98% Slit Response Function (SRF) test.

Most of the manufacturers today use the pixel method and commonly suggest that it takes 3 adjacent pixels for measurement (three horizontally and three vertically so it's actually 9 pixels in total that are required for measurement). For manufacturers that use this approximation method this means that the object must be 3 times larger than that specified by the spatial resolution specification (IFOV). Alternatively it means that for an object of a specific size you must be 3x closer than the detection limit for accurate measurement. Not all manufacturers use the 3X rule and even if they do some will not guarantee it. I've always wondered what would happen if one of those three pixels is a 'dead' pixel (yes Virginia your camera does have dead pixels) but that's a topic for another day!

Actual measurement resolution may also be defined by a 95% or 98% Slit Response Function (SRF) camera test. This is a test whereby the camera makes a measurement on a high emissivity surface (typically a blackbody) at a distance and size sufficient that it is as accurate a measurement as possible (typically 20 to 30 times larger than the IFOV). Then a vertical aperture, represented by two moving plates is closed in front of the blackbody until the signal falls by either 2% or 5%. Note that this is a drop in signal and not temperature. The use of a % drop in signal is simply a way of dealing with the term 'reasonable' accuracy. 98% (or 2% drop in signal) is a more stringent specification than 95% (or 5% drop) but can pose some challenges in conducting a

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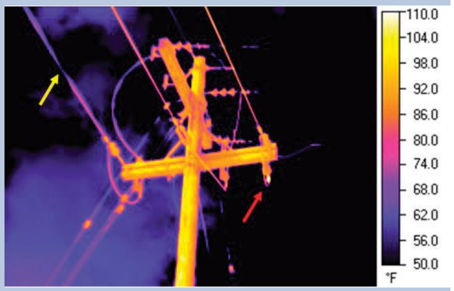
Real World IFOVm Example

The following is an image of a hot spot on a pole mounted connector. (red arrow). Notice the far line appears to be much cooler (less than 15.5 C, 60 F) even though it was a very warm summer day (32 C, 90 F). Notice also that the line 'appears to get cooler' where the adjacent foreground is clear sky rather than cloud. (yellow arrow) The significance of this? Because we are beyond the IFOVm the surroundings are influencing the measurement. Even though we are able to detect the line we are not able to measure it correctly. Even the adjacent lines are probably running a little cooler than they really are (they are closer to us because we were forced to look on an angle and the third line is further away). In all likelihood then the hot spot is also beyond the IFOVm. How should we report our findings about the hot spot? "That the temperature is at least the value being reported". This illustrates why thermography is so much more powerful than spot radiometry. This type of image analysis is also what we teach in our Level II and Specialty classes.



Measurement Resolution (IFOVm)

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repeatable and meaningful instrument test.

Students conduct an IFOVm test as part of our Level II Advanced Thermographic Applications class. In defining our test method we decided that we would set up the test so that the students could return to work with a meaningful number for IFOVm which they could expect from both themselves and their camera in the field. After hundreds of these class tests in the past few years we can definitively report that many cameras typically perform close to this 3X pixel approximation.

Lately we have been noticing an interesting trend. Some cameras are achieving much better than the 3X rule and a few much worse (and a lot worse). When we see a better result (like 2x) we still encourage the student to still use the 3X rule as a 'factor of confidence.' But when we see a bad result we usually ask the student to do it again since there could be a number of reasons including: they didn't check focus; had too much camera movement; didn't take a good initial reading, the camera had not stabilized; the camera averaging function was turned on, etc. A repeatable bad result, however, is worrisome. It may indicate that something is wrong with that specific camera, or even worse it could indicate a production problem or design compromise. We have seen a 320 x 240 focal plane array system in class having about a 2X IFOV value perform almost as well as a 640 x 480 camera with close to a 4X IFOV value. Needless to say, in that class we had one student very happy with his camera and one not so happy!

Measurement resolution may also be stated as a Distance to Spot (D:S) ratio. This is commonly used for spot radiometers and defines the distance away an object 1 unit high can be detected. To convert IFOVm to D:S simply take the IFOVm value in mrad and divide it into 1000. So a camera with a 4 mrad IFOVm would have a 250:1 D:S ratio (compare this to your average inexpensive spot radiometer with a 10:1 D:S ratio). Remember that whenever using either D:S ratio or milliradian values the units of distance must be the same (e.g. mm, inches, feet, etc.).

In the field, how can you recognize when you are in that 3X 'non measurement zone' between detection and measurement? An easy way is to change your distance, refocus and see if the measurement changes. If you move closer (only if it's safe!!!) and the temperature goes up on a hot spot or if you move further away and the temperature goes down, this is often a good indicator that you are in the 'non-measurement zone'. In this case, a maximum temperature function in your camera is useful rather than using a spot meter.

Now regarding the questions I mentioned at the beginning of the article. First, ***"If I can detect a hot spot why can't I also measure it accurately?"*** The answer, quite simply, is that the detectors (pixels) on your FPA cannot touch one another. They must be physically separated to prevent thermal and electrical cross-talk. There is dead space between the detectors. So some of the infrared emitted from an object falls on the detector and some will 'fall through the cracks.' Because part of the small object radiation falls on the detector, you see the pixel light up on the screen (i.e: you can detect a hot spot). Until an object is large enough to illuminate multiple pixels we cannot get a reliable and consistent signal value (in other words there is much more detector area than crack space).

Second, ***"If I am reading low why can't the camera correct for it?"*** This is a great question since it might be possible to (crudely) correct for it, but only if you know the object size, its shape, and how far away you are. I actually have a correction curve from 1978 produced for my old AGA 750 which did try to produce a correction factor for both a small circular and an oblong object when using different lenses. But I haven't seen anything like it from any manufacturer lately, and I can't use this

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old one because any correction factor will be camera and lens specific.

Finally, ***"Isn't that what the distance value in my camera corrects for?"*** No, this value simply corrects for the signal attenuation due to atmospheric absorption. Not even this small correction factor is radiometrically significant when using the long wave spectrum at reasonably close distance (10 metres). Yet the IFOV correction could be huge when say looking at a 5mm object at 5 meters.

If measurement is important to you then determining your IFOVm application requirement is essential before you buy a camera. You should determine the smallest object you need to measure and at what distance. Once known, you should have the sales representative validate in writing that the camera model and lens that you are considering will be adequate for meeting your measurement size requirement accurately. And remember IFOVm is only one of many factors which may result in inaccurate measurements.

Attending one of our Level II classes will be an opportunity to participate in a real-world discussion about all of the factors that influence measurement.

Designing and Constructing Effective Infrared Routes

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time can be wasted traveling to a location and then finding the equipment is not in operation or running during a low load period. This type of route spells out the conditions necessary to optimize infrared data collection. This type of route could be used for standby, redundant and back-up equipment or during staggered production cycles.

Routes by viewpoint are used to view a target from an atypical vantage point. When our objective is obscured, physically difficult or unsafe to approach, we need to become creative in the way we view that target. For instance, you may look around for a balcony or an overhead catwalk that gives a good viewing position. From that vantage point you may find there are enough additional targets to build a single route associating them only by viewpoint.

Routes by time or weather are used for those situations that require specific weather conditions for optimum results. Many types of infrared inspections depend on either the presence or absence of certain climatic and/or solar influences on the surfaces we are analyzing. Two good examples would be a roof moisture survey which demands the presence of solar heating versus outdoor electrical equipment which works best in the absence of any solar influence. Time can also be the primary factor, such as inspecting fire protection pumps that run only during their monthly testing.

As you determine which type of route is appropriate for your situation be careful to avoid any of these common mistakes:

- **Don't overlook safety**. Perform a walk-down of a planned route looking not just for order and efficiency but also being attentive to safety concerns.
- **In route design, bigger is not better**. Rather than having one large route break it down to manageable segments that will take two to four hours to complete.
- **Be adaptable**. Over time the type, frequency, size and order of the route should be a continuous collaborative effort of management, supervision, planners and thermographer. If a route can be made safer, more effective or efficient, change it.

At times you will find that it is advantageous to creatively combine the basic types of routes. This image of the transformer above offers one such example. Getting a good top view of the transformer was impossible at ground level during the normal outdoor electrical substation scan. The only appropriate vantage point was a rooftop view from an adjacent building. Unfortunately, it took over thirty minutes to get there by climbing up and down several levels of roofs with equipment in tow. A perceptive thermographer realized that while performing his rooftop heaters motor route, all he had to do was simply turn around at an existing data point and image the transformer. Even though unrelated, combining this one viewpoint with the existing route by equipment type made a significant improvement in safety and efficiency.

Make these six types of routes the framework for your routing plans and design but keep in mind that a truly great route always welcomes the creativity of knowledge and experience.

Jim Fritz, Principal
The Snell Group

Infrared Windows and Viewports

We are seeing the use of infrared windows and viewports more and more these days. These devices are mostly used for safety reasons when conducting infrared electrical inspections. Properly used, one assumes it is easy to often get good radiometric data doing inspections. Or should we?

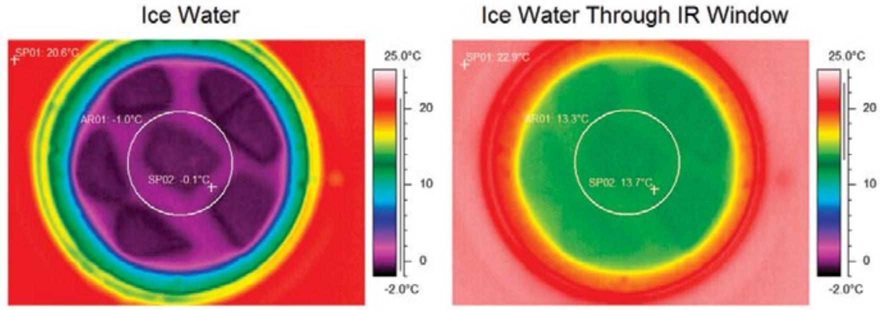
In my opinion, many of the infrared camera manufacturers have overlooked one of the more critical features needed on a thermal imager to conduct such an inspection! Too many cameras do not have a setting for optical transmission loss, either in the imager or analysis software. Such a correction must be used to obtain accurate radiometric measurements through a filter or an infrared window. I have even heard of some individuals (as well as a few sales representatives) incorrectly telling thermographers to adjust emissivity down to compensate for the optical transmission loss. I'm sorry to say it, but this does not work!

For example: let's say we are looking through an infrared window that has a transmission rate of approximately 70%. If we are inspecting a component on the other side of the window that has an emittance of 0.8, the temptation is to reduce your emissivity setting down to 0.56 to get the right value (.7 x .8 = .56) to measure temperatures. However, by lowering the emissivity value we have told the camera to also change the reflectance value from .20 (1.0 - .8 emissivity = .2 reflectance) to .44 (1.0 - .56 emissivity = .44 reflectivity). This makes the background value much more significant in the equation which is obviously wrong and not the case.

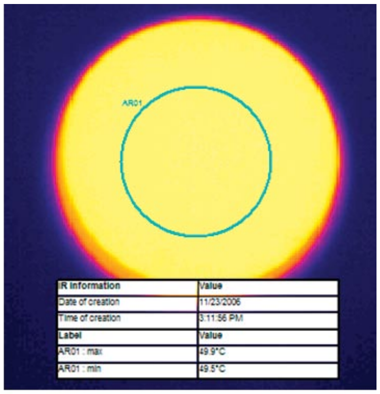
So what do you do if you want to make radiometric measurements through an infrared window? If your particular camera or reporting/analysis software can correct for optical transmission, set the value to the appropriate transmission rate for the window you are using. Depending on the situation, you may also need to input the temperature of the window itself. If your camera or software does not allow for correction what do you do to get accurate measurements? I hate to tell you this, but the answer is nothing! It cannot be done by changing other parameters.

So I encourage all of you to look at your analysis software or camera settings right now and see if it has this feature. If not, I would suggest you write or call your camera manufacturer and ask that this feature be added. As infrared windows gain more prominence in the marketplace, the camera manufacturers must keep up by providing us with the proper tools we need to do our job.

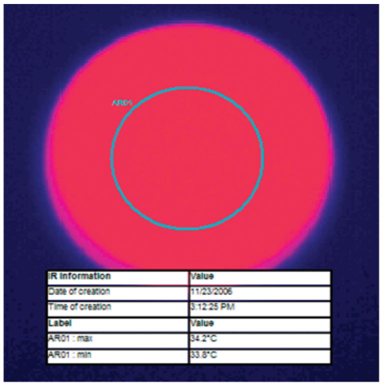
By the way, the topic of measurement corrections is a rather complex subject that can involve many factors. While that department is not necessarily my forté, I had the luxury of speaking with one of our resident experts, Greg McIntosh, in-depth about the subject. Greg will likely address these questions in a future issue of *Think Thermally*. For now, I encourage you to read his article on page 3 of this issue which addresses another important consideration for taking temperatures…measurement resolution (IFOVm).



When the window temperature is warmer than the object temperature, a high-emissivity object will appear (and measure) warmer than it really is. The left image is looking directly at ice water while the image on the right is taken through an infrared window.



Blackbody



Blackbody thru window

Thermal images of a blackbody radiator set at 50 degrees Celsius. The top image was taken while looking directly at the blackbody with the infrared camera (Area Max Temp.= 49.9 C). The bottom image was shot at the same distance while looking through an infrared window (Area Max Temp. = 34.2 C).

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A Simple Mind Contemplates Complexity

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as the work we do on buildings and machine assets makes a difference on the smaller scale, each little piece we change for the better has to help on the grander scale. Perhaps this is thinking too simplistically about a very complex problem, but I can't help believing our human systems are inextricably connected to the systems of the Earth. With our planet my simple mind tells me "turn on the AC" or "run it to failure" are not viable options.

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