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DELTA Solution Series - Part 1: Infrared Fundamentals

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When people are first exposed to infrared (IR), or thermal, imaging, they often struggle interpreting the images from the camera. They don't understand what they are seeing. Worse, those who then purchase thermal cameras do not get the most out of the investment.

This isn't because thermal imaging is incomprehensibly complex, but because it is a fundamentally different way of experiencing the world compared to what we see with our eyes. So, let's take some time to understand how thermal images are similar to, and different from, the typical drone visible-light camera.

What Is Infrared?

The first thing to get comfortable with is the fact that infrared cameras see a different type of energy than you see with your eyes. Human eyes – and a typical drone camera – see visible light, while a thermal camera sees infrared energy.

While visible and infrared are both parts of the electromagnetic spectrum, what differentiates them is the respective wavelengths. Electromagnetic energy travels in waves, so the wavelength is the physical distance from the peak of one wave to the peak of the next. In the infrared spectrum, these wavelengths are typically measured in micrometers, or a millionth of a meter. Visible light spans the waveband from 0.4-0.75 micrometers (often shortened to "micron" and abbreviated μm), while the infrared energy detected by most drone thermal cameras spans the 7.5 to 14 μm waveband.

These points provide the basis for some fundamental facts people need to understand when getting into thermal imaging. First, a given detector is only sensitive to – and can only see – a certain range of wavelengths. Human eyes and a typical drone camera are sensitive to and can therefore see visible light in the 0.4 to 0.75 μm waveband. Infrared energy's wavelengths are much too long for our eyes to see – that's why thermal cameras can "see the invisible."

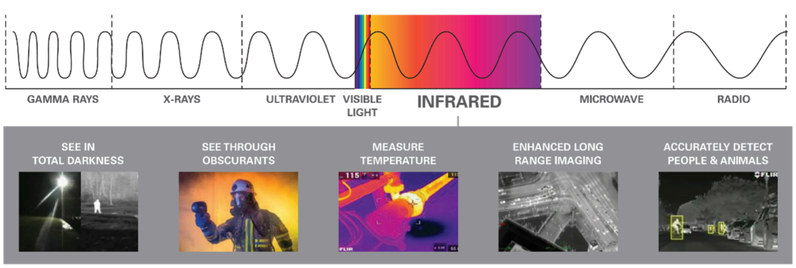

Figure 1: The electromagnetic spectrum includes the infrared waveband ranges from 0.75 μm in the near infrared to nearly 1 mm (1,000 μm) in the far infrared.

Next, the different wavelengths within the visible light waveband – often rightfully depicted as the colors of the rainbow – are interpreted by our eyes as that range of colors. Shorter wavelengths are the blues and violets, while the longer wavelengths are on the orange and red end of the spectrum. Because thermal imagers don't detect visible light, they don't detect color. Remember: color is a function of the visible light we see with our eyes, and infrared energy is invisible to our eyes.

Because of this, we must assign false colors, shown as different color palettes in a thermal camera, to the varying intensities of infrared energy detected by the camera. That's what people see with a thermal camera: varying intensities of infrared energy that come (mostly) from the surface of the object in the scene.

So, right there we have a couple of significant differences between visible light and infrared energy – we can see visible light but we can't see infrared; and, the wavelengths within visible light equate to different colors, while infrared can't see color at all. Start by remembering that a thermal camera is detecting and displaying differences in intensities of infrared or heat energy, not actual color, representing a big step towards understanding infrared imaging.

Heat vs Temperature

We've been talking about infrared energy and referring to it as heat energy. The next thing that can trip people up is confusing heat energy with temperature. They're not the same thing. When something looks "hot" to a thermal camera, that just means it's giving off more heat energy – it may be a higher temperature, and it may not. So, what's the difference?

All the molecules that make up everything on earth are oscillating. As heat energy is added to a substance, its molecules will oscillate faster and create more friction between molecules, and therefore increase the substance's temperature. What we see with a thermal camera is the amount of heat energy coming off something, not its temperature.

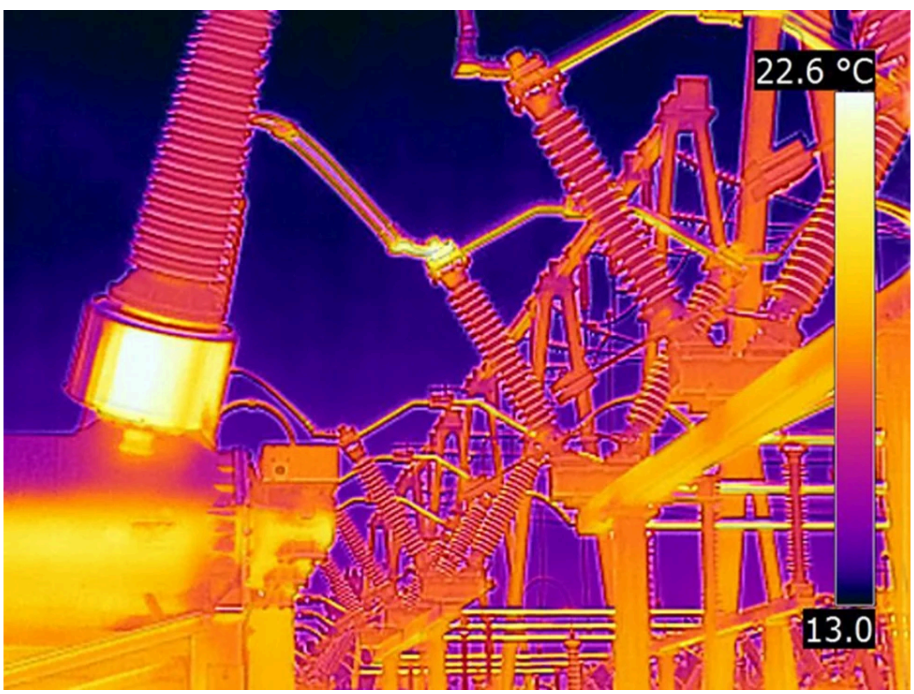

Figure 2. Radiometric thermal cameras calculate temperature

Temperature can be thought of as the result of having more or less heat energy in a substance. If we add heat energy, temperature will go up. If we remove energy, temperature will go down. Because our cameras detect heat energy, we must remember that the temperature values we see on an infrared image are *calculated*, not detected. And those calculations are impacted by a few very important variables that not only influence how hot something looks, but its measurement as well.

What Makes Something Look Hot or Cold?

First, remember that – for the most part – the infrared energy we see coming from an object is coming from the object's surface; but that energy isn't necessarily coming from the object itself. It could be coming from the object, but it could also be reflected off the object, passing through the object, or a combination of all three of these. In order to properly interpret an image and measure the temperatures contained within it, we first must understand where the energy we're seeing is coming from. Everything we see in an infrared image is some combination of emitted, reflected, and/or transmitted energy. We can show this relationship mathematically as follows with one representing 100 percent of the IR energy in the scene.

$$E + R + T = 1$$

1. **Emitted (E)**: Energy that is coming from an object directly is called emitted energy. This is energy contained in the object and being radiated from it.
2. **Reflected (R)**: Reflected energy is thermal energy that originated from something else but bounces off the object seen within the camera viewfinder.
3. **Transmitted (T)**: When energy from something behind the object passes through that object of interest, that material is said to be "transmissive." That means, the energy seen is being transmitted from the object of interest, not emitted from it.

The good news is that relatively few things are significantly transmissive to infrared energy, so most things are a combination of emitted and reflected energy (E+R=1). The bad news is that an object's transmissivity to infrared energy can be exactly opposite of what is expected based on the human experience with visible light. For instance, thin film plastics like tarps and garbage bags are highly transmissive to infrared to the point we can see through those objects with a thermal camera, but they are opaque to visible light. Conversely, normal window glass is highly transmissive to visible light (or they wouldn't make very good windows), but they are almost entirely opaque to infrared.

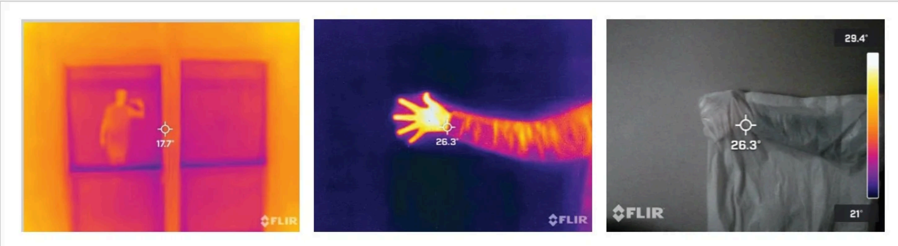

Figure 3. Thermal cameras can see reflections in glass and through thing plastic sheet/film

This is one of those things that trips up new operators – not only can one not see through glass with an infrared camera, one will often see reflections in the glass in infrared. To properly interpret a thermal image, operators must know what they are looking at, and its thermal properties, in order to understand if the energy that looks like it's coming from that object actually is coming from that object.

This is equally true whether trying to understand which things are hot in an image ("qualitative" inspection), or trying to get actual temperature measurements ("quantitative" inspection).

How Hot is "Hot"?

Earlier we discussed how heat is the type of energy we see with a thermal camera, but temperature is a result of having more or less heat in the object. Then we said that heat energy is either emitted (given off) from an object or reflected (bounced off) from an object. All these variables impact how hot something looks, and how accurately it can be measured.

The measure of how efficient an object is at radiating its heat is called its emissivity. Emissivity is a ratio of the energy in an object compared to how much energy it gives off, and these ratios are shown as values between 0 and 1.0. Therefore, an object that is 90 percent emissive has an emissivity of 0.9. Remember also that everything we see is some combination of emissive and reflective, so if an object is 90 percent emissive, it is 10 percent reflective. How emissive or reflective an object will be determined by the following six things, in decreasing order of importance:

- **Material** – Emissivity is first and foremost a material property. What the thing is made of will be the largest driver of how efficiently it gives off its energy. Organic objects – dirt, rocks, wood, animals (including people) are highly emissive, often with emissivity of greater than 0.95.

- **Surface finish** – The smoother and shinier an object is, the lower its emissivity and therefore the higher its reflectivity will be. For instance, if we take a rough piece of wood and polish it smooth, it will lower its naturally high emissivity and raise its reflectance. Conversely, shiny metals are naturally very reflective, but once they corrode, they become more emissive.
- **Viewing angle** – When viewing high emissivity objects from too shallow an angle, it will become more reflective. This is especially important for drone operators because we can easily change the tilt angle of our thermal cameras. Make sure to look at something at as close to a 90-degree angle as possible relative to the surface to minimize reflections.
- **Geometry** – Objects with lots of holes and angles in them can appear hotter than they really are because of those changes in geometry.

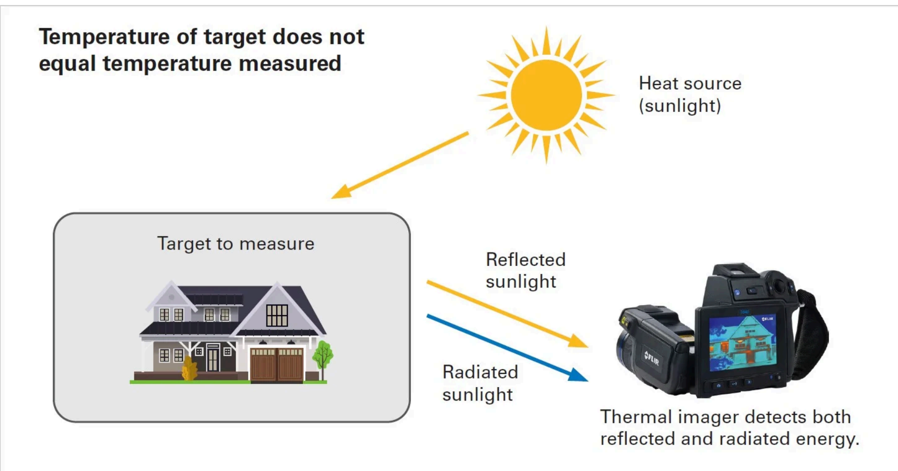

Figure 4. Thermal imaging cameras measure both the reflected and emitted heat energy

When measuring temperatures with a thermal camera for a quantitative inspection, all of the above variables need to be compensated for to generate what's called a true temperature. The other option is to generate an apparent (or, uncompensated) temperature, which we will discuss in DELTA Solution Series Part 2. We'll also cover how these different factors can influence common drone thermography applications, so stay tuned!

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