



INTRO TO THERMAL IMAGING

SEE THE WORLD IN A DIFFERENT LIGHT

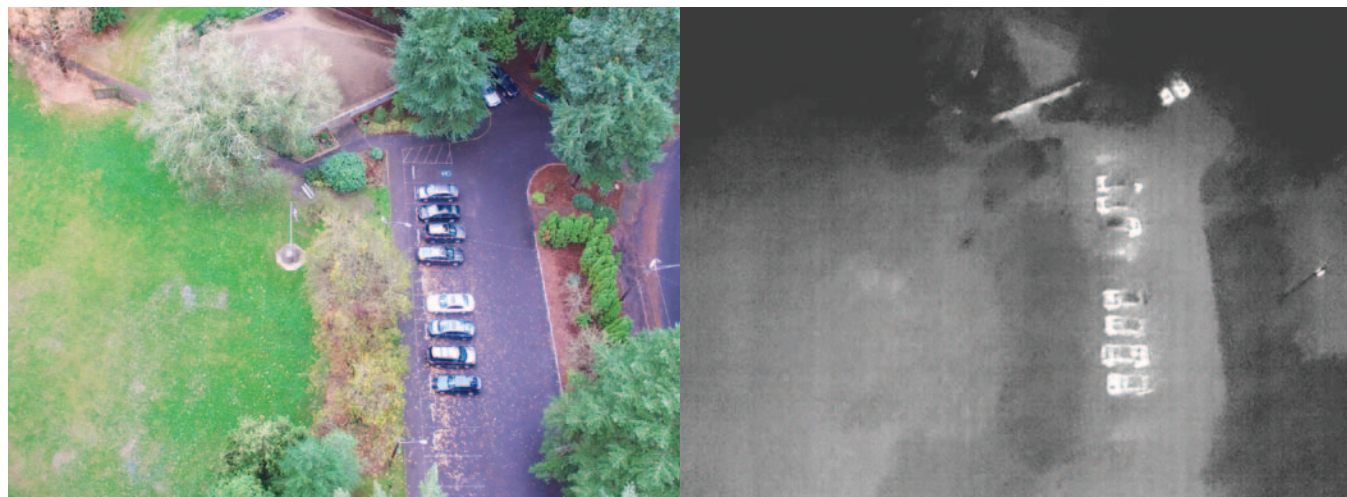
BY PATRICK SHERMAN

Equipping your drone with a thermal-imaging camera is exactly the same as mounting an ordinary visible-light camera, with one crucial difference: the wavelengths of the photons its sensor detects. Apart from that, everything else works exactly the same, even though you are seeing the world in a whole new way.

To understand the pictures produced by a thermal-imaging camera, let's first take a moment to understand how we perceive visible light, either with a conventional electro-optical (EO) camera—military-industrial-complex jargon for a video or digital still camera—or even our own eyes. We see the world around us when our retina absorbs photons either emitted or reflected by an object in the environment. Objects that emit visible light include the sun, lightbulbs, and computer screens, and objects that reflect light include every material substance in the universe. An EO camera works in exactly the same manner, substituting an electronic sensor for our retinas.

As Sir Isaac Newton taught us, the different colors we perceive are the result of variations in the wavelengths of the photons. Those with the longest wavelengths we perceive as the color red, and those with the shortest wavelengths appear violet to our eyes; in between lies the familiar spectrum of the rainbow. Of course, visible light is just one narrow slice of the much wider electromagnetic spectrum. The shortest wavelength belongs to the potentially deadly—and Hulk-creating—gamma rays, measuring a single picometer, or one trillionth of a meter. The longest are extremely low frequency radio waves, with wavelengths up to 100,000 kilometers.

The wavelengths that lie just beyond our visual perception are called “ultraviolet” and “infrared,” depending on whether they are shorter or longer than the corresponding visible spectra. What a thermal-imaging camera allows you to do is perceive a portion of the infrared spectrum as if it is visible light. You can recognize familiar shapes—people, cars, trees, and buildings—but instead of perceiving emitted or reflected light, what you are actually seeing is emitted or reflected heat.



HEAT WAVE

Needless to say, this change alters your perception of the world in ways that are both subtle and profound. The first thing to understand is that different temperatures have no colors intrinsically associated with them. Consequently, the camera must assign colors where none exist, and you can alter them depending on the specific circumstances and your own preferences.

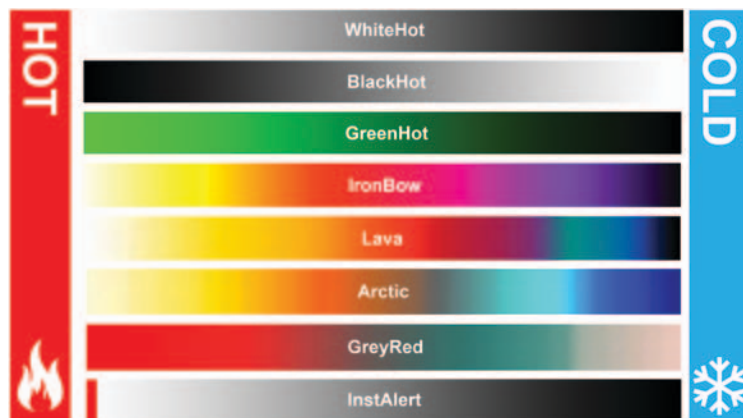
All thermal imaging cameras incorporate a number of predefined color palettes, which determine how temperatures will be represented. The U.S. military commonly employs a "black-hot" color palette, where the warmest object in the camera's field of view appears to be black and the coldest appears to be white. Civilian search-and-rescue teams often rely on the opposite: a "white-hot" color palette. Numerous other options exist, with names like "Arctic," "Fusion," "Rainbow," and "IronBow," although many of these are often reserved for applications such as industrial inspection and scientific research. The human eye and the human mind seem best able to identify familiar shapes, like people, vehicles, and structures, when rendered as a black-and-white image.

Another critical factor affecting how we perceive the environment through a thermal-imaging camera is its ability to discern and display the infinite range of temperatures that exist in the world. Whereas the human

Study this aerial image of a parking lot at a park to determine which of the 10 cars arrived first. This task is impossible using the visible-light image (above left) but comparatively simple using the thermal image (above right). The thermal image was captured in the white-hot color palette.

eye can detect 10 million different colors, the type of thermal-imaging cameras typically used onboard drones can only display 256 different values—whether spread among shades of gray ranging from black to white or a more exotic range of colors provided by an alternative palette.

That could be a substantial limitation on the technology's real-world applications, except that thermal-imaging cameras make the best possible use of those limited variations.



The spectra revealed by the thermal-imaging camera do not have any intrinsic colors associated with them, so the camera itself assigns colors to the temperature variations it reveals. The user can choose between a number of predefined color palettes, which determine how he or she will see the world.

NIGHT AND DAY

Imagine that you are called to assist firefighters at the scene of a traffic accident, where a car has skidded off a snowy road and struck a power pole supporting a high-voltage transformer. The impact has toppled the pole and the transformer has ruptured, sparking a fire that has engulfed a nearby shed. The firefighters, however, are mostly concerned about the driver of the car, who is missing. They believe that he or she might have been

ejected from the vehicle during the collision, and that person is now lying unconscious and injured, freezing to death somewhere in the surrounding underbrush. Whether the driver lives or dies depends on how quickly you can find them. You launch your drone, which is carrying a thermal-imaging camera set to display the "white-hot" color palette. What do you see?

The hottest thing in its field of view is the fire, burning



Thermal-imaging cameras incorporate a set of preprogrammed color palettes, which determine how variations in temperature will be displayed. The user is able to change color palettes as needed to deliver the most useful image, given the particular details of a situation and subject.



In this aerial image of a grade school, notice the details that are invisible to the electro-optical camera (above) that nevertheless stand out to the thermal-imaging camera (right)—such as the people playing basketball under the shelter as well as the fact that one of the heat exchangers on the roof is operating, near the right edge of the frame. Thermal image captured in the white-hot color palette.

WHEREAS THE HUMAN EYE CAN DETECT 10 MILLION DIFFERENT COLORS, THE TYPE OF THERMAL-IMAGING CAMERAS TYPICALLY USED ONBOARD DRONES CAN ONLY DISPLAY 256 DIFFERENT VALUES.



Seen in flight, this DJI Inspire 1 stands out against the cold sky in the white-hot color palette. Notice that the coniferous trees in the background are also warmer than the sky: a result of absorbing the sun's life-giving rays, even on a chilly winter day.

at 500 degrees Fahrenheit, so it appears white on your video downlink. The coldest thing is the snow-covered ground, at 0°F, so it is black. One way that the camera could allocate the 256 shades of gray that it has available between these two extremes is to divide them evenly—about 2°F per shade.

While that makes intuitive sense, it would “waste” much of the available variation on temperatures that do not exist within the camera’s field of view. There is essentially nothing between the temperature of the fire and the next warmest subject in the frame: the bare faces of the first responders, at about 85°F. Yet an even distribution of the available shades of gray across this scene would allocate about 80 percent of them to this temperature range.

Instead of an extremely inefficient “even” distribution, thermal-imaging cameras dynamically assign those limited variations where they will provide the most benefit for you: where small differences in temperature are crucial—such as identifying the driver, partially buried in the snow.

Also, notice that one key detail is missing from this

THERMAL IMAGING SOMETIMES GETS LUMPED TOGETHER WITH NIGHT VISION—AND IT WILL ALLOW YOU TO SEE EVEN IN TOTAL DARKNESS—BUT IT WORKS EQUALLY WELL IN FULL DAYLIGHT.

scenario: the time of day. So far as the thermal-imaging camera is concerned, the difference is irrelevant. Thermal imaging sometimes gets lumped together with night vision—and it will allow you to see even in total darkness—but it works equally well in full daylight.

KNOW YOUR LIMITATIONS

Thermal imaging is a powerful tool, but it isn’t magic. There are limitations as to what it is capable of accomplishing, and it is important to recognize them. If you watch movies and TV shows about international secret agents, then you have probably seen something purported to be a thermal-imaging camera gazing effortlessly through walls.

The truth is that walls block thermal photons just as effectively as visible-light photons. Indeed, while glass is transparent to visible light, it blocks thermal emissions, so a thermal-imaging camera can’t even see through windows—a distinct disadvantage compared to an EO camera. Thermal imaging, however, can see through smoke, which obscures visible light—one reason that it is such a popular tool for firefighters—although suspended

The Company behind the Camera

FLIR is the world’s largest commercial manufacturer of thermal-imaging cameras—so large that it exceeds the volume of cameras sold by all of its competitors combined. With nearly 3,000 employees worldwide and annual sales exceeding \$1.6 billion, the company is headquartered in Wilsonville, Oregon. Established in 1978, FLIR’s initial goal was to conduct home energy audits to improve efficiency in the wake of the OPEC oil embargo. That mission quickly expanded to include the development of low-cost thermal-imaging systems for airborne applications. A decade later, the company had begun to leverage its expertise to enter new markets, including portable and laboratory systems.

Today, FLIR serves the consumer market with products like the FLIR ONE, which transforms an Android or iOS phone into a thermal-imaging camera. It also provides systems for industrial, technical, scientific, public safety, and military applications—ranging from rugged handheld systems to stabilized gimbals for manned helicopters and fixed-wing airplanes.

FLIR FOR DRONES

To serve the rapidly expanding civilian drone market, in 2015, FLIR launched its Vue line of thermal-imaging cameras, based on its proven Tau camera core. The most recent Vue camera models, the Vue Pro and the Vue R provide easy setup and configuration using integrated Bluetooth and a mobile app available for both Android and iOS smart devices.

Integration into existing drones is easily accomplished with PWM inputs to control basic camera functions, like onboard recording and color-palette selection, as well as a MAVLink



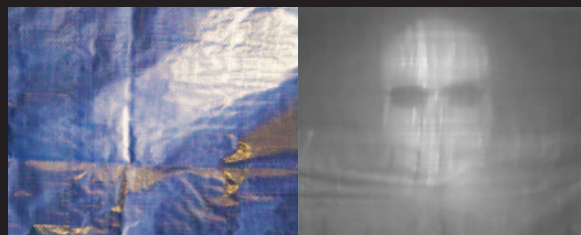
FLIR, the world’s largest commercial manufacturer of thermal-imaging equipment, specifically developed its Vue line of cameras to serve the small civilian drone market—making available capabilities that were once limited to military platforms.

interface to support image capture and geotagging for mapping and survey missions. Vue thermal cameras have received industry recognition, including a 2016 Consumer Electronics Association Innovation Award and a 2015 award for Drone Innovation at the IoT Evolution Expo. To learn more, visit flir.com/suas.



Different materials affect visible-light photons and thermal photons differently, as revealed in this pair of images. An ordinary pane of window glass reveals the face of a subject for the EO camera (left) while obscuring it for the thermal-imaging camera (right). Thermal image captured in the white-hot color palette.

THERMAL IMAGING CAN SEE THROUGH SMOKE, WHICH OBSCURES VISIBLE LIGHT, ALTHOUGH SUSPENDED MOISTURE IN THE AIR, LIKE CLOUDS AND FOG, BLOCKS BOTH.



A waterproof blue tarp completely obscures the face of the person sheltering behind it (left). However, the same material is semi-transparent to the thermal-imaging camera, making a ghostly image visible through the material (right). Thermal image captured in the white-hot color palette.



As this thermal image captured using the white-hot color palette reveals, materials in the environment can absorb warmth from external sources and re-radiate it, even after the source is removed—making it possible to see the footprints of a person who stood for a moment on a cold tile floor then walked away.



The heat radiating from the individual components of this DJI Inspire 1 reveals that it has recently landed. Viewed using the white-hot color palette, the motors, battery, and camera gimbal are noticeably warmer than the rest of the aircraft and the background.

moisture in the air, like clouds and fog, blocks both. In addition, certain materials reflect the thermal conditions in their surroundings. Just as it’s nearly impossible to determine what color a mirror is because it reflects the colors in its environment, a metal container will sometimes reflect the thermal properties of what is outside of it, rather than inside of it. Also, bodies of water, like lakes, rivers, and even puddles, most often reflect the sky rather than revealing anything about the temperature of the water.

Finally, there are limitations of the technology itself. Whereas an EO camera can operate continuously and produce clear, consistent images, the sensor inside a thermal-imaging camera needs to undergo periodic recalibration, a process called “flat-field correction.” Without this, the image will degrade over time until it became unreadable.

The elapsed time between calibrations is determined

by a variety of factors, including the ambient temperature, airflow around the camera, and how long it has been operating. As a general rule, the frequency decreases after the camera has been powered up for several minutes.

It’s a completely automatic process, and it involves a neutral thermal target passing between the sensor and the lens for a brief moment. Of course, during that time, the camera cannot see what is happening, so it displays a still image of the previous frame until the process is complete. Flat-field correction typically takes less than a quarter of a second, and you will receive a warning in the form of a symbol that appears in the upper right-hand corner of your display immediately before it happens—but it can be a bit disconcerting until you get used to it.

A NEW PERSPECTIVE

It can be painful for a hard-core drone fan like myself to admit it, but the revolutionary power of drones lies not in their whirling propellers and UFO-like maneuverability nor their mechanical simplicity and robust reliability but, instead, in their ability to position a sensor in three-dimensional space. Even I have to admit that’s what drew me into the nascent world of drones all those years ago, and whether they’re monitoring crops, making movies, or assessing storm damage, drones have allowed us to see the world from a new perspective, heretofore impossible in all of human history.

Provided that you understand how it works and what it can’t do, thermal imaging adds a potent new capability to the already formidable list of things you can accomplish using your drone. Now, let’s get out there and use them to make the world a better place! 🚁