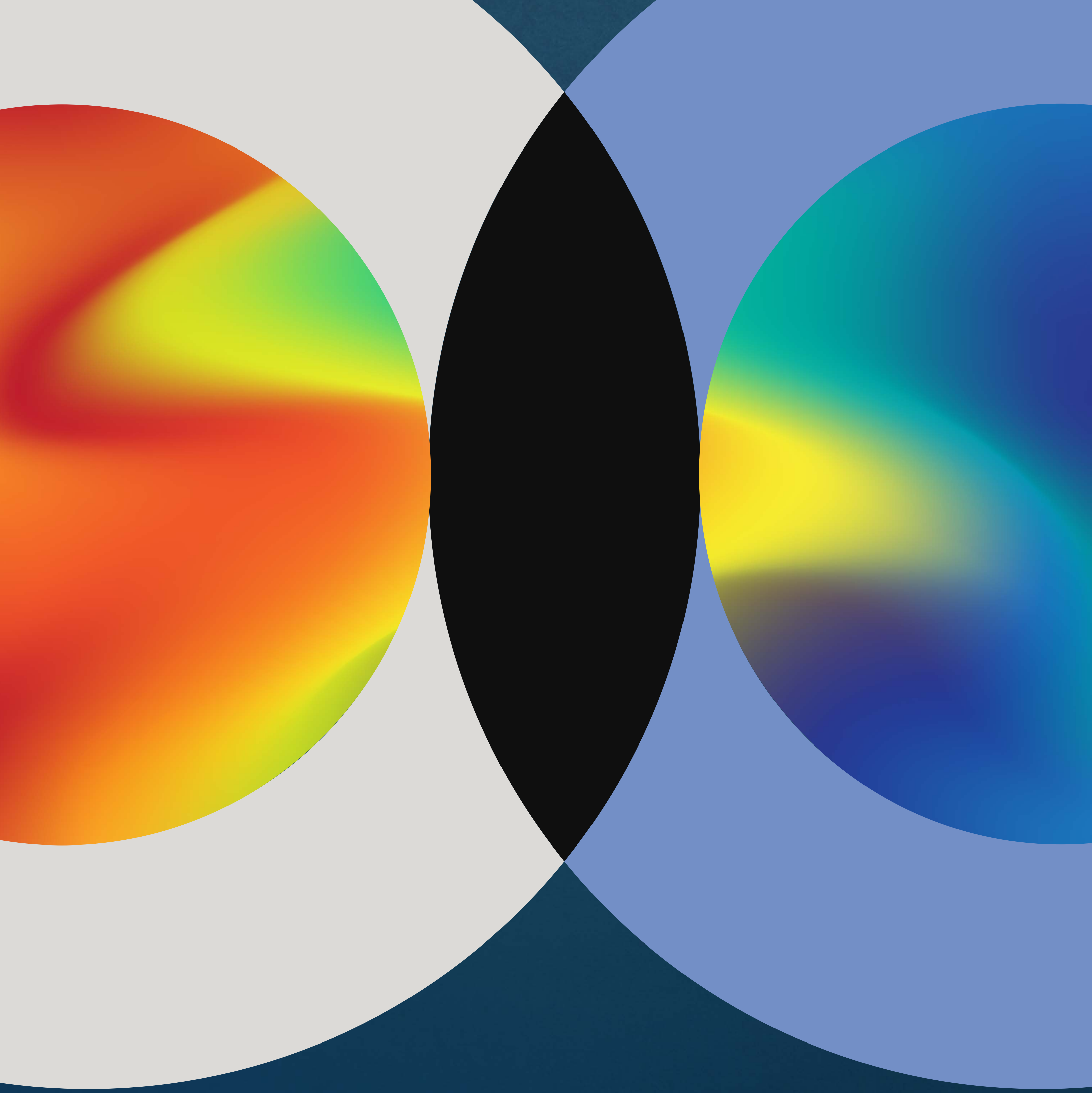

OWL AUTONOMOUS IMAGING • 2023

12 MYTHS

and FALLACIES about THERMAL IMAGING FOR CARS

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MYTHS AND FALLACIES ABOUT THERMAL IMAGING FOR CARS

Public concern over rising pedestrian deaths at night has focused the attention of automotive manufacturers and regulators on the failure of automotive pedestrian automatic emergency braking (PAEB) systems to work when the sun goes down. During the day, the current combination of video cameras and radar works well but, at night when the cameras can't see, radar has insufficient spatial resolution to locate pedestrians alone. LiDAR has been proposed as an adjunct but low repetition rates and difficulties seeing through fog and rain would limit the improvement.

Decades of experience in surveillance and defense have shown that thermal imaging in the infrared should be able to address all of the current system shortcomings but until now the assumptions that cost, bulk, complexity, and operating constraints would prevent adoption of this technology in automobiles have delayed widespread automotive implementation. Fortunately, the premises on which these assumptions were built are largely no longer true. Herewith is presented a dozen of these premises and an assessment of their current validity.

PREMISE

#1. THERMAL CAMERAS DETECT TEMPERATURE

Sensors in thermal cameras detect electromagnetic energy in the mid- or long-wave infrared bands. For most applications like surveillance, inspection of heat leaks, firefighting, and locating people in the dark, the benefit from thermal cameras comes from their ability to distinguish small differences in temperature in common environments. Those differences are detectable by thermal infrared sensors because the energy emitted by various objects changes with temperature enough so that the sensors can form images.

Note that in all of the examples listed, determination of absolute temperature is not critical; an image of just the temperature variations provides sufficient information to make decisions. In applications requiring absolute temperature values such as medical examinations and process control, thermal cameras can be designed to support calibration to the appropriate precision and accuracy. Even in those cases, a visual temperature map can provide additional details on the extent of thermal features, outlines of energy flow and low-temperature anomalies.

In PAEB applications, the goal is to detect and classify pedestrians and animals and other vulnerable road users (VRUs) and to compute their distances from the automobile soon enough to avoid collisions. Temperature difference information is sufficient for this purpose.

Since thermal imagers detect energy, not temperature, concern might arise that active sources, like headlights and the sun might cause confusion. Fortunately, the amount of energy from such sources in the infrared bands used is small compared to the emissions from pedestrians. Even in daytime, thermal images are much less confusing than visible images.

Even in well-lighted areas, thermal images denote pedestrians far more clearly than visible images. Lights from signs and cars do not interfere and the software can distinguish pedestrians from car mufflers.

PREMISE

#2. IF THE AIR TEMPERATURE OUTSIDE IS 98.6 DEGREES, THERMAL CAMERAS CAN'T SEE PEOPLE

The infrared bands used for thermal imaging were selected precisely because the atmosphere is transparent to electromagnetic radiation in those bands. Certainly, the molecules in the atmosphere emit radiation just like solid objects, but the density of gases is so low that the atmospheric contribution to the image is insignificant. A person standing on a beach with nothing but sky behind stands out just as in a visible image. In the unlikely event that the person stands in front of a building with a wall at a uniform 98.6˚F, just the small variations in body temperature are sufficient to provide a definitive image. In fact, the skin temperature is likely to be significantly below 98.6˚F due to evaporation of the perspiration produced in reaction to proximity to a hot wall.

More interesting is the situation in cold environments, where people are likely to be bundled up so much that the outer surface of the clothing takes on a temperature close to that of the ambient air. It is common in winter scenes for only the hands, feet, and faces of well-bundled people to be clearly visible in thermal images. However, even then, enough of the clothing will be above the ambient temperature for typical thermal cameras to outline the person just because the person continues to produce metabolic heat that raises the clothing temperature.

Thermal imaging can reliably detect people even when the air temperature is 98.6˚F such as on this summer day in Detroit.

PREMISE
#3. "THERMAL CAMERA" IS JUST ANOTHER NAME FOR "INFRARED CAMERA"

Generic "infrared" cameras detect radiation in some part of the infrared spectrum that runs from roughly 900 nm to beyond 15 microns. Thermal cameras are usually infrared cameras that detect in the 3-5 micron (MWIR) or 7-14 micron (LWIR) bands and report their images in terms of gray or false-colored images representing temperature variations. Both those bands produce images showing thermal variation around room temperature. The reader is referred to our white paper Volume 2 for details on band selection.

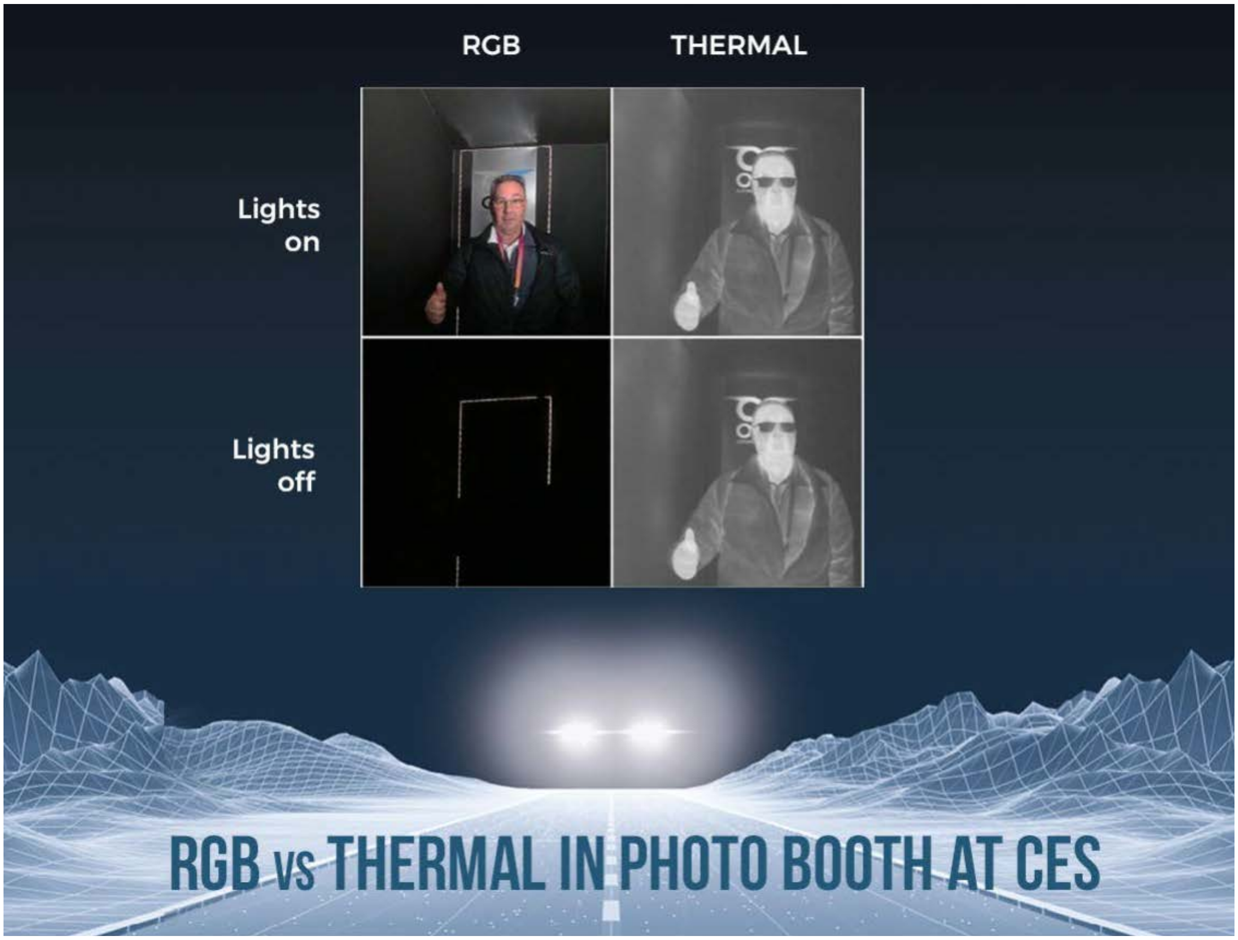
Some industrial applications like metals and glass processing where the temperatures are higher, produce usable temperature-mapping images at shorter wavelengths. However, usually "thermal" cameras are those that are intended to produce images of objects around room temperature.

PREMISE
#4. THERMAL CAMERAS CAN SEE IN THE DARK

To humans, "seeing in the dark" implies that the lights are off and the moon is new. Physically, this means there is little electromagnetic radiation in the 400 (violet) to 700 (red) nm band available. Thermal cameras can see under those conditions if the objects present have slightly different temperatures from each other. Warm objects, like people and animals, stand out like beacons.

Other warm objects like car engines can also be seen by the camera but artificial sources cannot be seen unless they emit in the detected bands. The people can be sorted from the other warm objects by the viewer or by appropriate computer software. If there are no warm objects, as may be the case in, for instance, surveillance of a parking lot after everyone has gone home, then it may not be possible to discern any objects because the thermal emission is uniform. To a thermal camera, this is truly dark.

In the automotive world, "dark" means the absence of active illumination. This can be the sun, street-lights, headlights, or specialized sources like laser illuminators for LiDAR or even radar transmitters. Thermal imaging requires none of these. Thermal images are formed by collecting radiation emitted from the object being viewed.



PREMISE

#5. IT IS EASY TO HIDE FROM THERMAL CAMERAS

Hiding from a thermal camera means eliminating temperature variations that can be seen by the thermal camera. Standing behind a brick wall might work because the thermal mass of the wall is so much larger than an individual's thermal mass. Standing behind less substantial barriers might not work because a layer of plywood could, for instance, be warm enough from body heat to show a detectable temperature variation. The same effect would soon reveal people hiding behind materials that absorb infrared such as glass and many plastics. Standing behind an infrared reflecting foil might hide a person but the individual would be heated by the reflected energy and become uncomfortable.

Further, attempting to move while carrying the barrier would usually be obvious in the thermal images because of variations in the temperature of the barrier itself against the background. While classifying the moving object as a person might not be possible, security systems generally attach suspicion to anything that moves, regardless of configuration.

In traffic, intentionally hiding behind an insulation barrier is unlikely to be a wise course of action so the real concern is that selection of clothing of some sort might fool the classification software. As it turns out, no matter how much you bundle up, your thermal signature still contains enough information to permit a PAEB system using thermal cameras to protect you.

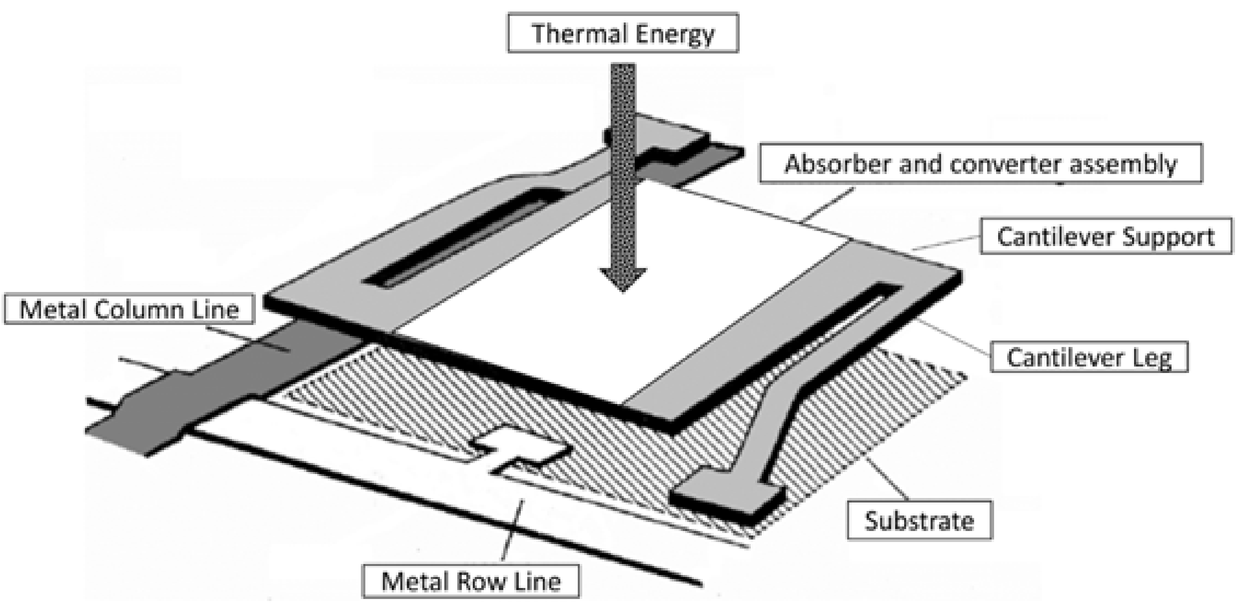
PREMISE

#6. THERMAL CAMERAS NEED REALLY LOW OPERATING TEMPERATURES

Two methods are used to detect thermal energy. Both require low enough background noise to allow small temperature variations to be discerned. The first high-performance detectors converted photons to charge carriers directly, just as in silicon imagers. However, the energy of thermal infrared photons is very small compared to visible photon energy so the materials suitable for detecting them have very high dark current at room temperature. Initially, cooling to liquid helium temperature (4K) was necessary to reduce the dark current, with later detectors requiring only liquid nitrogen at 77K. Generally, these detectors are now mounted on Stirling coolers, which require no gas replenishment but are large mechanical devices. These are unsuitable for use in cars due to size, cost and reliability concerns.

Subsequently, a well-tested thermal conversion device called the bolometer was miniaturized. The resulting microbolometer, which operates by absorbing the thermal radiation and sensing the resulting temperature change in the absorber was suitable for manufacturing using semiconductor fabrication equipment. Microbolometers, while less sensitive to temperature variation than photon detectors still produce sufficient signal variation with changing temperature to allow image formation at speeds useful for video imaging.

Microbolometers can operate at room temperature and, because of their monolithic construction, can tolerate high vibration environments thus meeting the requirements for automotive use.



A microbolometer sensor element responds to incoming thermal energy with a change in resistance that produces a proportional change in signal current.

PREMISE
#7. THERMAL CAMERAS ARE BIG AND BULKY

Elimination of the Stirling cooler in microbolometers cameras reduces the required size and weight substantially, but one problem remains - microbolometers are subject to output variations resulting from changes in the temperature of the detector itself. To counteract this, solid-state thermoelectric coolers may be applied to stabilize the device temperature where the extremes are too great.

In many thermal cameras, a mechanical shutter is enabled to periodically close off the incoming scene to allow recalibration. Unfortunately, the shutter interrupts data flow and disrupts the continuous operation of the car's computer and its PAEB system. Owl has developed a different solution to temperature dependence, replacing the active cooling and external shutter with a self-calibration circuit that will appear in new sensors soon.

PREMISE
#8. TWO THERMAL CAMERAS ARE NEEDED TO MEASURE DISTANCE

One of the contributions of machine learning is the development of neural network configurations and algorithms that can extract distance information from single images. These techniques are agnostic to the source of the images and work as well with thermal data as they do with visible monochrome and color images. While the expected proliferation of visible cameras on cars precludes the necessity of using these techniques for distance measurement in daytime when traditional stereo calculations can be applied, the number of thermal cameras can be reduced to a minimum with the implementation of monocular thermal distance measurement at night.

In automotive use, the primary considerations are coverage of the areas around a car that are most likely to generate pedestrian collision hazards with sufficient resolution to support accurate classification and accurate calculation of distance from the car out to ranges that match the expected vehicle speed. Testing of prototypes of the Owl Thermal Ranger® system shows that both of these requirements can be met.

PREMISE

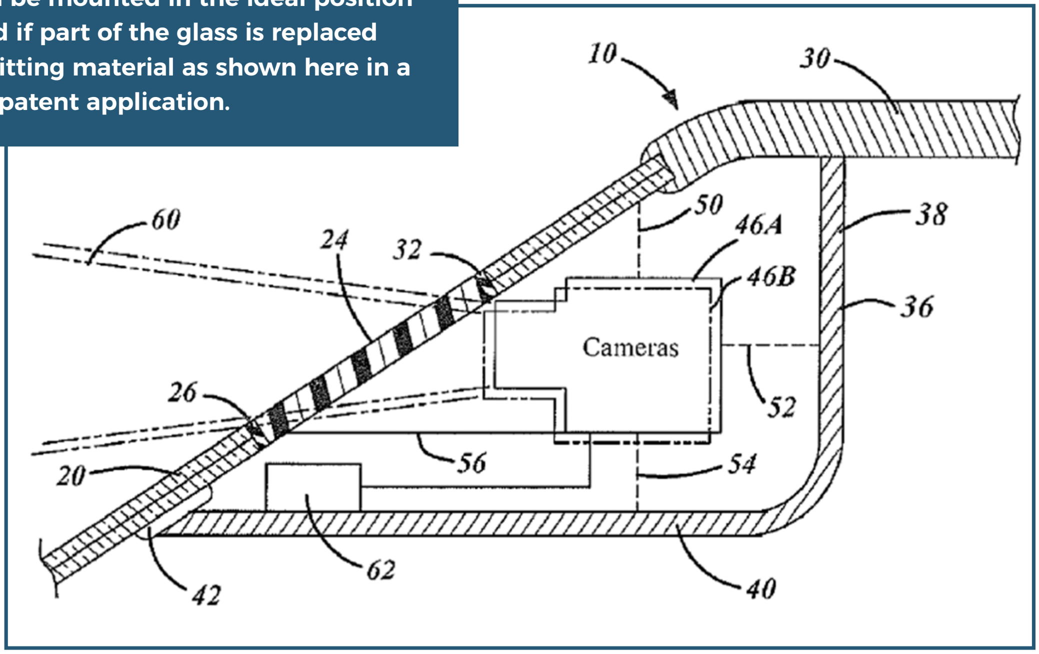
#9. THERMAL CAMERAS CAN SEE THROUGH ANYTHING, EVEN GLASS

The bonds between atoms in all materials have characteristic energies that result in absorption of photons at those energies. The result is that the materials appear opaque. This phenomenon can be seen in the plot of atmospheric transmission where the bonds between atoms in the various gases inhibit transmission in certain wavelength regions and essentially define the atmospheric windows where infrared imaging is practical. The two bands useful for thermal imaging are roughly mid-wave infrared (MWIR) at 3-5 μm and long-wave infrared (LWIR) at 7-14 μm.

Liquids and solids have similar regions where transmission is blocked. Water, for instance, will not pass much outside the ultraviolet and visible bands (probably not a coincidence when compared to what humans can see). Common window glass blocks everything outside 300-2000 nm, explaining why cars get hot inside in summer with their windows closed. Neither of these ubiquitous materials is compatible with thermal imaging. Thermal camera lenses must be made of silicon or germanium or chalcogenide materials or one of the few crystalline materials like zinc selenide that pass the right bands but don't absorb water.

Initially, these material restrictions seemed to mandate that a thermal camera required mounting outside the vehicle in little enclosures with appropriate infrared-transmitting windows. The ideal location would have been on the roof just above the rear-view mirror. Rising to the challenge, windshield manufacturers have recently demonstrated glass with infrared transmitting inserts that permit a thermal camera to be placed inside the vehicle behind the rearview mirror. Benefits include improvement in cost, durability, performance, and even consistency in image quality because the windshield wipers can be configured to keep the thermal view clean.

A thermal camera can be mounted in the ideal position behind the windshield if part of the glass is replaced by an infrared-transmitting material as shown here in a Ford Motor Company patent application.



PREMISE

#10. THERMAL CAMERAS CAPTURE TOO MUCH DATA FOR A CAR'S COMPUTER TO HANDLE

Luckily, adding neural networks to the computer mitigates this problem. In the new generation of automotive computer architectures, the raw camera data in digital form travels to a central computer surrounded by dedicated zone processors. Thermal images intended for pedestrian location go to a neural network that finds the pedestrians, surrounds them with rectangular containers called bounding boxes, and labels them with location in the field of view and distance. This small data packet, probably in the form of robot operating system (ROS) messages, is all that needs to pass to the next stage that converts the pedestrian data into commands for action by the car. The main computer never sees the original image data.

In designs where the original thermal images are to be displayed for driver viewing, the video can be routed to the display where computer-generated location and range data are overlaid. Routing video signals through the computer is not necessary.

Neural network processing reduces this image from 330kb to about 30 bytes, a reduction of 10,000 to 1.

PREMISE

#11. THERMAL CAMERAS HAVE LOW RESOLUTION

Some thermal cameras—those used for boiler monitoring and fever detection and other low-resolution tasks—have low-resolution (up to perhaps 120 x 160) sensors but these are not suitable for pedestrian location. Fabrication technology is not the limitation because it can incorporate many of the techniques used in the defense industry to make silicon sensors almost as big as a whole wafer. The question then becomes, "What resolution is needed for appropriate imaging in cars at night?" Careful analysis of the resolution required to provide reliable recognition of pedestrians at safe distances with curb-to-curb coverage indicates that something in the realm of megapixel HD sensors is needed. Since megapixel sensors with appropriately small detection elements can be readily fabricated, the resolution question can be answered.

But then the next myth arises:

PREMISE

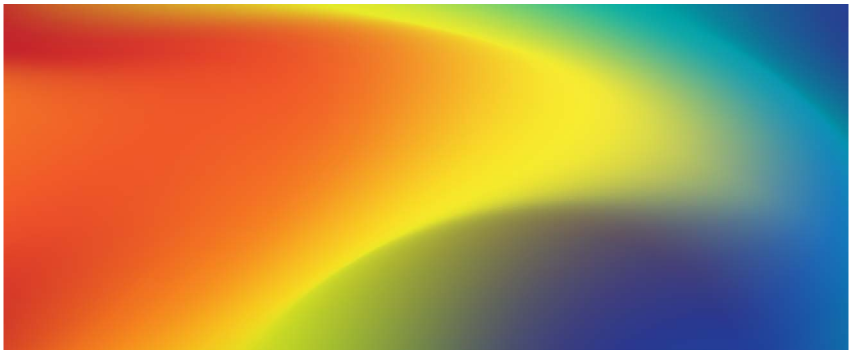
#12. THERMAL CAMERAS ARE SO EXPENSIVE THEY CAN ONLY BE USED IN LUXURY CARS

Microbolometer technology has already yielded megapixel sensors for defense use, but these would be too expensive for automotive applications. Even traditional microbolometers would be too costly because of the way they are manufactured and controlled. Now, a new design strategy developed at Owl can produce HD-class microbolometer sensors with integrated digital processing, automatic temperature compensation, high thermal sensitivity, and a size compatible with low-cost optics making production of thermal cameras for any car affordable. Look for availability very soon.

While we can all be grateful that surveillance and defense applications have been able to fund the development of high-performance thermal cameras, we can now be equally appreciative of the engineering efforts that have reduced the cost and size of thermal cameras enough to allow them to be included in the arsenal being deployed in cars of all classes to reduce the harm to pedestrians on the roads at night.

INFRARED AT OWL AI

With the goal of locating and identifying pedestrians at night even in weather-degraded conditions, Owl AI studied the spectral band options, evaluated equipment operating in candidate bands, tested the resulting images in an AI recognition system and, based on the results, selected diffraction-limited, high-resolution imaging in the LWIR band as the best way to meet the goal. A new image sensor incorporating the Owl AI research results now becomes the latest embodiment of the OWL AI principle Safety Starts with Perception™.



Safety Starts with Perception

YouTube LINKS

MORE ON THE MYTHS

Thermal Imaging in Winter: https://youtu.be/o2bzGyc6WAg

Hiding from a Thermal Camera: https://youtu.be/redhD3P7xrA

Comparing Images in Various Bands: https://youtu.be/zwZ13NGtlEU

Stupid Thermal Imaging Tricks: https://youtu.be/Fx49t4sv7f0

Getting Started with ROS: https://youtu.be/46TPAKXBOF8

DEMONSTRATIONS OF OWL AI TECHNOLOGIES

November 2022 NHTSA Nighttime Pedestrian Test:
https://youtu.be/wQ5VdMJPOvw

April 2022 Pedestrian Demonstration:
https://youtu.be/JaaTngahIms

January 2022 Pedestrian Comparison with Visible:
https://youtu.be/TmfzYcGRH_Y

November 2021 Pedestrian and Automobile Classification:
https://youtu.be/BMGLgnxNI6M

Example videos of our **THERMAL RANGER** in action can be found on our **YouTube Channel** at this link >>>

"OWL's THERMAL RANGER® is unique as it delivers rich detail and 3D response day or night."

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