Thermography and Computer Vision

Lab 58 Technology Research Brief

September 2021

The practice of capturing and analyzing data from thermal cameras is called thermography. Commonly referred to as "thermal imaging," thermography captures infrared radiation (IR) waves or heat as images—allowing users to see an object's heat radiating off itself. Thermal cameras (also called thermographic cameras, IR cameras, thermal imaging cameras, or thermal imagers) record the temperature of various objects in the frame and then assign each temperature a shade of a color, which lets you see how much heat is radiating compared to objects around it.[1] This technology can be used in combination with computer vision (CV)[2] technologies to allow for automated measurements of heat in a flexible, cost-effective, and contact-free method. This brief highlights the foundations of thermography, integration of thermography and CV technology, and use cases for the combined technologies.

Applications of Thermography

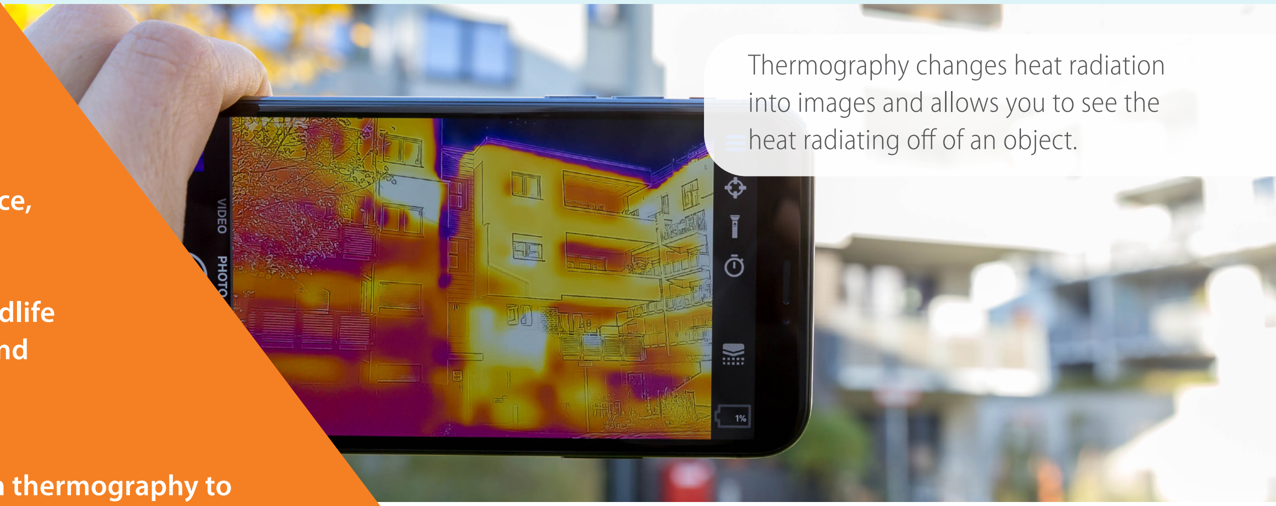
Thermography has been commonplace in the fields of medicine, security and surveillance, law enforcement, and defense over the past several decades, but the lowering cost of thermographic cameras and the increasing accessibility of CV allow these fields to (1) automate and expand their uses of thermography and (2) enable uses in new areas. These new areas include automotive and aeronautics industries, emergency response, surveying and construction, wildlife and agriculture management, as well as defense and security.

Key Takeaways

Thermal cameras use IR instead of visible light to create images.

Use cases for thermal cameras include aerospace, defense, automotive, manufacturing, farming, emergency response, wildlife management, security, and architecture.

CV can be combined with thermography to automate many use cases.



Thermography changes heat radiation into images and allows you to see the heat radiating off of an object.

1. Lloyd, C. (2017). "How Does Thermal Imaging Work?" How-To-Geek.
2. For more information about CV, see the Lab 58 Technology Research Brief, Computer Vision for Object Detection.

Conventional Cameras Compared to Thermographic Cameras

To understand how a thermographic camera works, let's compare it to a conventional (visible light–sensitive) camera (Figure 1). Conventional cameras are sensitive to the same part of the electromagnetic radiation spectrum as the human eye—shorter wavelengths starting at 740 nanometers (nm) (red) to 380 nm (violet). Thermal cameras are sensitive to a different section of the electromagnetic spectrum—IR (Figure 2). Any object with a temperature above 0 Kelvin (-273°C or -460°F) gives off an amount of IR (heat energy). The IR spectrum ranges from 1,000 micrometers (µm) to 760 nm, but real-world conventional cameras cannot capture radiation from the entire spectrum. For example, the FLIR E54 thermal camera can accurately measure IR with wavelengths from 11.45 µm (-20°C or -4°F) to 3.14 µm (650°C or 1,202°F)—well beyond the wavelength detection of a conventional camera.[3] Thermographic cameras will then apply a color spectrum to the heat image so that users can more easily interpret the visual image.

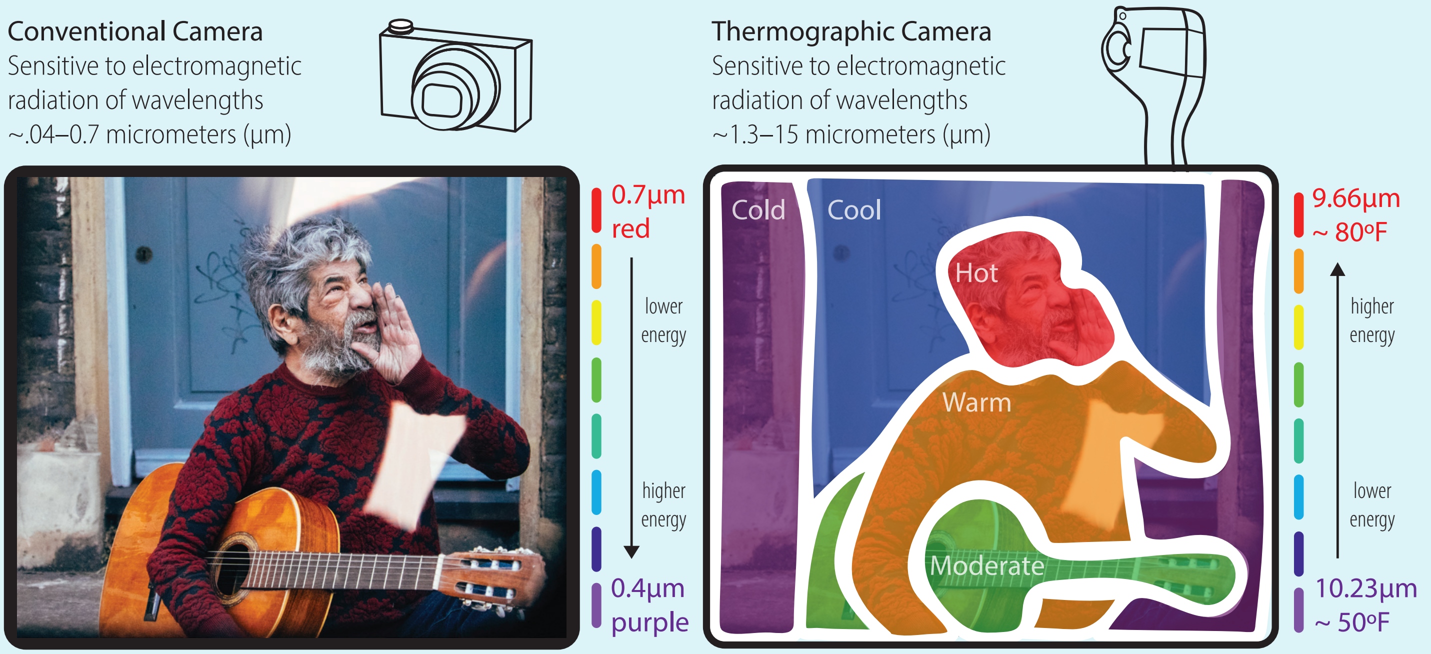


Figure 1. The images above compare how a conventional camera and a thermographic camera would visualize the same scene. The scales on the sides of the images show which colors correlate to which wavelengths of electromagnetic radiation.

Mechanics of Thermographic Cameras

A thermal camera consists of a lens, a thermal sensor, processing electronics, and mechanical housing. The thermal sensor itself contains numerous tiny measuring devices called microbolometers that capture IR. Each pixel has a microbolometer. The lens focuses IR energy onto the sensor. The microbolometer records the temperature, and the device's computer assigns that pixel to an appropriate color. Colder temperatures are commonly a shade of blue, purple, or green; warmer temperatures are represented with a shade of red, orange, or yellow. The resulting matrix of colors is sent to memory and to the thermal camera's display as a thermal image of that object.[4]

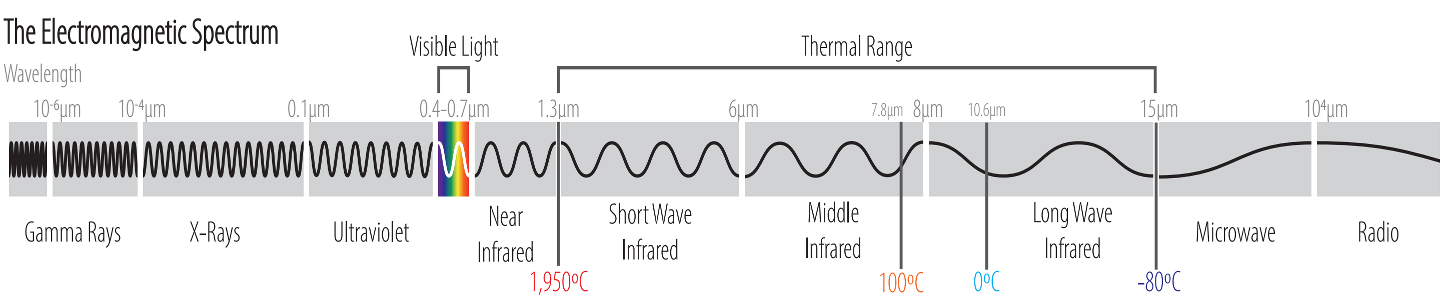


Figure 2. Visible light and IR exist on the same spectrum known as the electromagnetic spectrum.[5] The spectrum depends on the wavelength of the radiation and it can be anything from very short gamma rays to much longer wavelength radio frequencies. The range of the spectrum that thermographic cameras can interpret as heat is known as the "thermal range."

3. Sas, W. (2020) "Wein's Law Calculator" OmniCalculator
4. Teledyne FLIR. (2020, June 16). How do thermal cameras work?
5. Britannica (2019) Electromagnetic Spectrum. Encyclopedia Britannica

Types of Thermographic Cameras

Thermographic cameras come in many different shapes and sizes, and each has different strengths and weaknesses to fit a variety of needs.

Handheld Cameras | FLIR E54

Sensitive Range: **-20°C to 650°C** | Retail Price: **$5,000** | Resolution: **320 x 240 px**

Handheld cameras, such as the FLIR E54 (specs shown above[6]), come in several different shapes, but all offer high-fidelity thermographic capabilities in a portable package. Some models come in the thermal "gun" shape, but others may look more like a digital camera or camcorder. Handheld cameras are frequently used for building inspections because they can quickly identify hotspots in electrical systems, detect water leaks, check insulation efficiency, and more. Prices can range from a few hundred dollars for entry-level models, but advanced models (like the FLIR Exx Series) can exceed $15,000.

Uses: Surveying and inspection, firefighting, agriculture, health care, veterinary medicine[6]

Pros: Professional-quality inspection gear; lots of variety between models to find an ideal model for your uses.

Cons: Custom CV integration would need to happen retroactively.

Attachable Cameras | Seek Thermal Compact PRO

Sensitive Range: **-40°C to 330°C** | Retail Price: **$499** | Resolution: **320 x 240 px**

Peripheral cameras, such as the Seek Thermal Pro (specs shown above[8]), are cameras that attach to a smartphone through Micro USB, USB-C, or the Lightning (iOS) port. These cameras are low-cost, small, and lightweight, which make them ideal first cameras for those starting to experiment with thermography. Despite their $200–$500 price range, these cameras offer very good sensitive range and resolution for most uses.

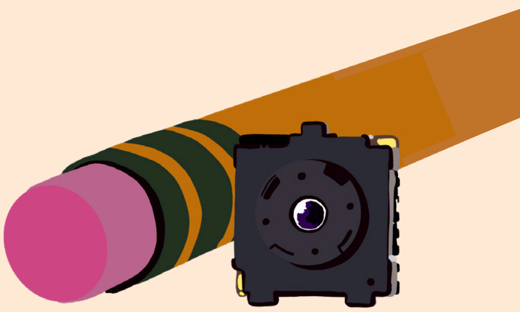
Uses: Do-it-yourself home inspection, small-scale business uses

Pros: Affordable price point geared toward personal research or small-scale retail use; pocket-sized and easy to use with mobile devices.

Cons: Custom CV integration would need to happen retroactively.

Thermographic Modules | FLIR Lepton 3.5

Sensitive Range: **-10°C to 400°C** | Retail Price: **$199** | Resolution: **160 x 120 px**



Thermographic modules, such as the very tiny FLIR Lepton 3.5 (specs shown above[9]), aren't complete thermographic cameras on their own, but they are components designed to be used by engineers and developers to create their own custom thermographic systems. Due to their small size, modules are popular choices for attaching to drones. Modules can be built directly into systems that can perform CV tasks in real-time.

Uses: Research and development, integration into drones and other devices, custom solutions

Pros: Low cost; lightweight and low-profile; built for researchers and developers to build custom thermography solutions, including CV applications.

Cons: Not a standalone device; requires supplemental tech to be usable; lower resolution.

6. Teledyne FLIR. (n.d.) FLIR E54.
7. Reduction Revolution. (2021) Thermal Cameras
8. Seek Thermal. (n.d.) Powerful thermal imaging cameras designed for your smartphone.
9. Teledyne FLIR. (n.d.) Lepton®.

Setting Up a Thermographic Camera

The following paragraphs provide additional information about the steps for setting up a thermographic camera.

1. Install thermographic camera.

Select an appropriate thermographic camera; before setup, ensure the camera is charged or connected to an external power source. To properly orient the device for more efficient use, mount a handheld camera or connect it remotely to a smartphone application.

2. Test the output display.

The camera's ability to output thermal images accurately needs to be calibrated and tested before data collection can begin. Start by examining the camera for any errors before surveying the capture area for potential obstructions, glass, and/or other shiny objects that will block footage. Next, point the camera at objects with known temperatures to check if infrared data are properly displaying. If IR images are accurately captured and displayed, then the camera is ready for data collection.

3. Begin data collection.

You may wish to view a live feed or store photos and videos for later review. Some thermographic cameras allow real-time object labels that are saved within video files before the captured data are exported for individual review or used in conjunction with artificial intelligence (AI) computer algorithms. This feature allows for ease of analysis when surveying multiple subjects.

4. Optional: Use with a CV Model

There are many ways that a CV model can be applied to thermographic images or videos. Depending on what functions you are looking to automate, your model will have to be customized for the specific application. For example, if you are looking to automatically measure forehead temperatures, you will need an algorithm that is trained to identify a human face, then identify the forehead region of that face, then extract and display temperature information from the forehead region (Figure 3). This process can vary widely depending on the use case but is explained more generally in the next section.

Figure 3. Thermography and CV can be used to identify if anyone in a crowd is exhibiting fever symptoms. The CV algorithm searches the image for human faces, and once identified, can extract temperature information from the correct places on the thermographic image. Many people can be monitored simultaneously in a subtle, reliable, and contactless way.

Integrating Thermography and CV

Thermography allows us to "see" beyond the capacity of the human eye—even in the dark. We can add this concept of superior sight to CV, which allows computers to "interpret" images in three steps: (1) acquiring, (2) processing, and (3) interpreting.

1. **Acquiring.** Images can be acquired in real-time through video, photos, or 3D technology for analysis.
2. **Processing.** Deep-learning models automate much of this process, but the models are often trained first by being fed thousands of labeled or pre-identified images.
3. **Interpreting.** This step involves identifying or classifying an object.

After these three steps, a decision is made based on what we have "seen" and "interpreted." Understanding scenes in this way requires a combination of CV, thermal imaging, and AI. The AI serves as the system's "brain." It can learn, adapt, consider alternatives, and come up with new strategies for interpreting and analyzing a scene.[10]

One area where AI really stands out is solving ill-structured problems that may involve many complex and related variables—something conventional algorithms struggle to do. AI is ideal for these "nondeterministic" problems (i.e., random events influenced by unpredictable human behavior) for which the solution can be different each time the problem occurs.

Examples of AI's ability to solve unpredictable problems[11] include the following:

Photo by Manoj Mohan, Lab 58

Figure 4. A CV algorithm places facial feature markers over a thermographic image. This process allows for pinpointed temperature tracking at many distinct facial regions.

- **Medical.** IR temperature measurement systems powered by AI algorithms have been developed to increase the effectiveness of temperature controls. AI can detect and measure temperature on a person's face and other areas that best indicate core body temperature—all without physical contact. These temperature controls are fast and contactless.
- **Autonomous driving.** Pictures of roads in urban, rural, and other environments are uploaded to databases and used to improve autonomous perception in different traffic conditions. The flow of images from a vehicle's two sensors is captured and feeds the AI algorithms that power different vehicle systems. Figure 4 above demonstrates how the captured images must be annotated so that algorithms can learn from them. Here, deep learning is used to automatically model the gathered data so that AI can learn them, ultimately improving applications for IR technology, such as obstacle and pedestrian detection.
- **Counting endangered wildlife species.** Thermal imaging can detect the presence of animals at night and in various terrains (Figure 5). IR-equipped drones can fly over remote areas or areas with thick vegetation to locate and count the animals in difficult terrain. CV can be used to automate animal identification and counting tasks.

Combining the fields of thermography and AI to CV has resulted in vast improvements to the CV field in less than a decade. Today's systems are more accurate than humans at quickly detecting and reacting to visual images.

Figure 5. Thermal images can be used to quickly locate animals in environments where they may be naturally camouflaged.

Images from CoolCosmos, CalTech.edu

10. SAS Institute Inc. (n.d.). Computer vision: What it is and why it matters.
11. Lynred. (2020, October 10). How AI and infrared technology can be used together in industrial settings.

Considerations for Successful Thermographic Imaging Applications

Technical Feasibility

The ability to take thermographic images dates back to 1929. Since thermography was developed for military use almost 50 years ago, commercial and industrial use of thermography has continually increased. The advent of deep learning AI has sparked continued research and development, with focus on improved cost, display resolution, capture speed, accuracy, and predictive reliability. Researchers should thus apply the following technical considerations before thermographic camera use:

- **Accurate predictions require thorough model calibration before use:** Computer algorithms used in conjunction with thermography must be appropriately calibrated and trained for any machine/deep learning analysis to be considered reliable. This can pose issues to anyone who might not have sufficient resources or expertise to operate thermography with machine learning.

- **Thermographic technology is still costly:** Although machine learning algorithms are usually open source, they often will require experts to customize the application. An incredibly modest setup could be made with just a thermographic camera and an adequate computer, but high-performance systems and professional equipment can quickly become cost prohibitive.

Operational Limitations

When implementing new technology in any use case, there are always some operational limitations to keep in mind. The relevant limitations for thermographic cameras are as follows:

- **Certain spaces may be improperly displayed:**[12] Any area that reflects or distorts heat or light waves will not be properly visualized by the thermal camera (Figure 6). For example, glass tends to reflect heat; as a result, shiny or reflective spaces—including transparent surfaces—can disappear from the image. Environmental factors—such as temperature, terrain, and natural disasters—may also distort thermographic images due to their heat effects.

- **Uncontrollable variables can affect image results:** Confounding environmental factors—such as temperature, terrain, and natural disasters—may distort thermographic images due to their heat effects.

- **Thermographic cameras have accuracy limitations:** Most manufacturers state accuracy up to the larger of +/- 2°C or +/- 2% of their full sensitivity range.[13] Uses that require extreme precision may demand other types of sensors.

Images from Spitzer.Caltech.edu

Figure 6. Comparison of a thermal image (right) and an ordinary photograph (left). Some materials are transparent to infrared light, while opaque to visible light (note the plastic bag). Other materials are transparent to visible light, while opaque or reflective to the infrared (note the man's glasses).[12]

Ethical Appropriateness

It is also important to weigh any ethical concerns before testing imaging technology. The following key factors should be considered before thermographic camera and CV usage:

- **Avoiding sole reliance on the technology for making important decisions related to health care:** During the COVID-19 pandemic, there has been a great amount of enthusiasm around thermography for disease identification in public spaces by pinpointing individuals that have a fever. Using thermography in this way may cause dangerous false confidence that an area might be "safe" from infected individuals. Although thermal scanning can identify elevated body temperature, it cannot soundly distinguish between fevers and other causes of elevated body temperature. Ambiguities could lead to numerous false diagnoses and unjust quarantine impositions during a pandemic.

- **Ensuring proper model training to avoid bias concerns:** The accuracy of these systems depends on careful setup and operation, as well as proper preparation of the person being evaluated.[14] Like all AI models, algorithms can be biased without comprehensive testing and inclusive representation in training materials. This bias may lead to harmful prejudice or enforcement of stereotypes.

12. Hurt. R, (2008). Hands in a Bag (color): Visible cs Infrared Light. NASA/JPL-Caltech
13. Infrared Camera Accuracy and Uncertainty in Plain Language. Teledyne FLIR, 12 April, 2016.
14. Thermal Imaging Systems (Infrared Thermographic Systems / Thermal Imaging Cameras). U.S. Food & Drug Administration, 12 January, 2021

Thermography and AI in Business

Thermography has many applications, and various business sectors utilize this technology. In the manufacturing sector, thermography is used on product assembly lines as a quality assurance tool—helping to identify defective units during production. In firefighting, thermal cameras can clear lines of sight through thick smoke clouds (Figure 7). The technology also records surface temperatures, providing firefighters with a low-risk option to monitor wildfire intensity. Deep-learning frameworks for thermography are trained to predict wildfire spread, identify hazardous flammable agents, and even detect liquid levels in nearby tanker trucks to prevent further disaster.

Figure 7. These images demonstrate the effectiveness of thermal images for seeing through thick smoke. The person on the floor is completely obscured in the conventional image on top, but they can clearly be seen in the thermal image on the bottom. Being able to clearly see in disaster scenarios could mean the difference between successfully getting someone to safety or not being able to help them in time.

Images from CoolCosmos, CalTech.edu

Future Directions

The joint future of thermography and CV is quite promising. Millions of dollars have been invested to ensure the technology will continue to improve, and it has accordingly garnered the interest of technology and business industry leaders alike. Thermal imaging systems are becoming more accurate and more affordable, leading to more widespread use. There are high hopes for CV and thermography to be a key technology that can be used to help prevent another global pandemic because thermal scanning technology is already being tested for COVID-19 surveillance. Tracking and controlling the spread of disease—as well as forest fires and invasive wildlife—may soon be possible with deep learning AI and thermal scanning technology.

Work with Lab 58

Thanks for your interest in our work! Our researchers and developers are actively exploring use cases for the combination of thermography and CV, and we want to help you explore opportunities to work with the technology.

Please email us at Lab58@rti.org. We will set up a 30-minute, one-on-one chat to discuss opportunities and answer any questions. We are interested in partnering with you to find a solution that meets your needs.

For more information, contact Lab58@rti.org.