Thermal Imaging and Human Identification

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Introduction

Cameras are used widely in our everyday lives these days, from digital cameras with big lenses optimized for capturing high detail in an image, to small cameras in our phones that we use to take casual photos of our pets. However, digital cameras operate differently from thermal cameras. While digital cameras operate by detecting visible light, Thermal cameras detect the infrared radiation of objects directly.

Thermal Imaging Background

The Wave Spectrum

All objects emit infrared waves known as thermal radiation. Infrared waves are waves that have a wavelength that is larger than visible red light, but lower than microwave light. The infrared spectrum is divided into the near infrared, and the far infrared. The near infrared spectrum extends from the end of the visible light region, which ends with waves that have an approximate wavelength of 0.7µm, up to waves that are 25µm in length. The far infrared spectrum extends from the end of the near infrared spectrum to 1000µm. As objects get hotter, they have more energy, and therefore the wavelengths they emit become shorter, as there is an inverse relationship between the wavelength of an electromagnetic wave and its energy. Moreover, as objects grow hotter, they emit more radiation as a whole across different wavelengths [1].

Infrared Visibility

The naked human eye usually cannot see the infrared thermal radiation projected by objects, as their wavelength sits outside the visible light spectrum. Hence, humans created thermal imaging technology, which is used to identify the heat signatures of objects based on their thermal radiation. Thermal cameras usually take advantage of this technology to produce a thermal image of objects that is visible to the human eye similar to a regular camera, in which hotter objects appear brighter, while cooler objects are usually less visible. This allows us to see hotter objects in images no matter the conditions, day or night.

History of Thermal Imaging

The first infrared scanning sensor was invented in 1947, however it was a far cry from the technology we use today, as one scan took around an hour to complete. The army saw the potential in this technology and its possible uses, and so they put a lot of research into this technology which saw rapid evolution, making it into the technology we see today [2].

Current Thermal Imaging Technology

Nowadays, Thermal cameras use sensors that are known as Micro-Bolometer Detectors. These detectors work by sensing the change in thermal radiation and sending that as a signal by modifying the current through the electrical circuits of the detector (figure 1). The speed of detecting this change in temperature is important, and this speed is determined by the thermal capacitance of the material used, the thermal conductance, and the mass of the detector [3]. This is why bolometer detectors are usually designed as membranes to lower the mass of the detector as much as possible, hence increasing the ability of the detector to measure temperature changes. Thousands of these Bolometer pixels work in conjunction to create a thermal image on thermal cameras, each detecting its own change in temperature. The accuracy and resolution of these cameras depend on the size of pixels used and their pixel density to create an image that can be viewed and interpreted by humans. Just as in visible light cameras, the smaller the pixels can get, the more that can be fit on a chip, which increase the resolution of the output image.

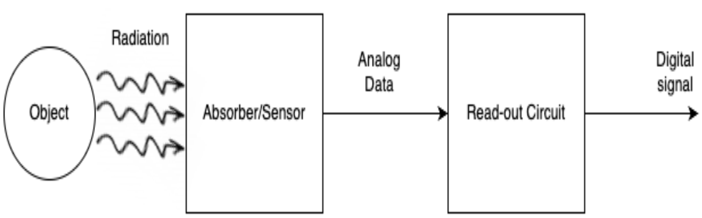

Figure 1. High level description of thermal imaging circuits

Bolometer Pixel Configurations

The Bolometer pixels are usually placed in a Focal Plane Array (FPA) fashion, FPAs are different from scanning arrays because they are two-dimensional arrays (figure 2), which help in image processing as opposed to the very narrow 2D arrays in scanning arrays. The temperature sensing materials that are used nowadays are mostly vanadium oxide (VOx), amorphous silicon (α-Si), and silicon diodes. These materials were chosen because they offer a high Temperature Coefficient of resistance (TCR), and a low noise value, in addition to being compatible to be integrated with read-out circuits if need be, in addition to reducing the noise passed to the read-out circuits [3].

In order to read the changes in thermal radiation of each pixel, the sensors need read-out circuits which transform the change in thermal energy into a change in resistance and current in the circuit, and these changes are then used to display the image on the camera's screen. The read-out circuit must be able to read the very small resistance change from every pixel, as well as being able to handle the noise from itself and the detector's noise. A 1998 paper [4] dives deeper into the design for an infrared detecting Bolometer and its read-out circuit (figure 2).

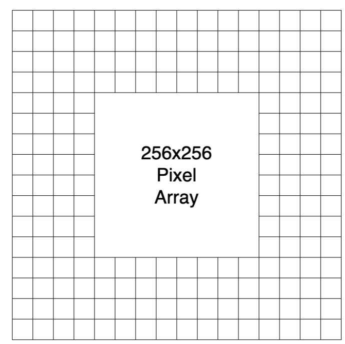

Figure 2. Example FPA Configuration, each square is a Bolometer pixel.

Thermal Imaging Limitations

Although thermal imaging is a great technology, it does not come without its own limitations. For example, when the Bolometer detects a change in temperature, it needs to register the change in temperature quickly, which means that it needs high conductance between the Bolometer and the heat sink [3]. Therefore, a higher heat capacitance for the Bolometer slows down the rate at which data can be sampled by the read-out circuit and the rest of the camera's components, which could lead to a low framerate in the camera's display. On the other hand, framerate is not usually very important unless very precise temperature measurements are needed, such as measuring the heat dissipation in high-speed circuits.

Another limitation for Thermal detectors is the amount of noise that is generated by the circuit, which the camera must be able to separate and distinguish from the real temperature readings of objects, which can be a hard task to accomplish [3].

Lastly, thermal cameras cannot measure the heat signature of highly reflective surfaces such as windows, mirrors, or even plastic. This happens because highly reflective surfaces reflect the heart signatures of other objects rather than letting their own thermal radiation be transmitted, and therefore thermal detectors have issues with these materials. However, some thermal cameras get around this issue by using special lenses that emit their own infrared radiation.

Thermal Imaging Applications

Nowadays, thermal imaging has a plethora of uses in many scenarios. For example, Thermal cameras can be used for normal tasks such as examining home insulation by pointing the camera at walls and seeing if any cold spots exist, or they can be used for more specialized tasks such as measuring the heat dissipation of electronic circuit components. Moreover, thermal cameras can be used to detect sickness symptoms such as breast cancer [5] and fever [6], which was greatly helpful for mass screenings during the heights of the COVID-19 pandemic.

Since the army was one of the early adopters and revolutionizers of thermal imaging technology, they also have a number of uses for it, such as night vision lenses for both people and military vehicles. However, firefighters are first responders in groups which are usually also equipped with thermal cameras [1], and that is the group we wanted to focus on for our project. Firefighters use thermal cameras to detect hidden fire sources, as the area around the fire would glow brighter on a thermal camera, making it easier to localize. Moreover, they can use the cameras to detect gas leaks and to find sources of heat such as humans in dark and smoky environments where it might be hard to locate them otherwise [1].

Relevance to Our Project

Since our project is focused on finding people trapped in void spaces after disasters, and since the void spaces would likely be dark and filled with smoke, rubble, and dust, then thermal cameras are a good choice for trying to detect trapped humans, as their heat signature would glow brighter than most pieces of rubble. However, since there might be fires breaking out in some void spaces, we will need a way to distinguish the heat signatures of fires than those of humans. In the original study our project was based upon [7], they used a thermal camera in their algorithm to effectively determine if the outline visible on the thermal camera was a human, along with information from other sensors.
In our design, we believe that having a first responder operate the thermal camera would be a good choice to ensure that they investigate sources of heat further, and they could better determine if the heat source was indeed a trapped human. Moreover, considering the fact that fires would likely burn hotter than a human's body, it would be easier to distinguish humans from fires based on their heat signature. We can also leverage the thermal camera's data to feed into an algorithm which detects the probability of the reading being a human, even for low resolution thermal cameras [8]. We will use our thermal camera in conjunction with a visible light camera to help the user navigate the bot as well as detect any human outline or movement. The visible light camera will be used mostly for navigation, but the thermal camera can be used to assist navigation in dark and smoke-filled environments where the visible light camera may not be as helpful.

Conclusion

Thermal cameras function by detecting the thermal radiation of objects in its view, and it uses the temperature change in the detector to change the current going through the circuits, leading to a signal that can be read by the thermal camera circuitry and hence allowing for a thermal image to be formed. Thermal cameras have many uses from everyday usage to military and firefighting purposes, and those uses can be extended further to help locate humans that are in danger, or are trapped in void spaces, which is what our project aims to achieve.

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