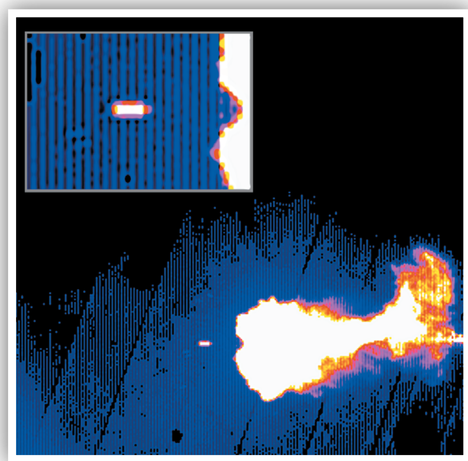
Thermography: Temperature measurement of an object by observation of its emitted radiation, primarily in the infrared waveband.

How to Measure the Temperature Of a Speeding Bullet

Infrared (IR) imaging technology offers a way to measure temperatures of objects that do not easily lend themselves to physical contact. All objects emit electromagnetic radiation, primarily in the IR waveband for objects at terrestrial temperatures. One of the most useful wavebands for thermography is the midwave IR, or MWIR band. Small changes in temperature produce large relative changes in flux, leading to increased thermal contrast over other IR wavebands, that in turns leads to more accurate temperature measurement.

The technique is as follows: A thermographically calibrated IR camera is pointed at an object of interest and an image is taken. Software takes the digital data from the detectors in the camera's sensor and converts these data into temperature values. In a typical calibration procedure, the camera is pointed at a blackbody source at known temperature. The response of the camera is repeatedly recorded as the source temperature is varied over a range of interest for a specific application, and a polynomial is fit to the data. This polynomial function can be used to calculate the temperature of an object for any temperature within the range of the calibration.



This MWIR image shows a bullet that has just emerged from the cloud, where the temperature would be at its highest. A close-up of bullet shown in inset.

The camera lens itself can contribute to the flux of IR radiation reaching the detector array. The lens contribution can be calibrated out at a particular temperature, but if the camera environment changes, then the apparent temperature of an object as viewed by the camera can change. Therefore, a thermographic camera should have temperature sensors in the lens housing or lens interface itself, so that the software that calculates the temperature of a source compensates for the IR contribution from the lens itself.

Recently, we measured the temperature of a rifle bullet in flight. This is an excellent example of an object whose temperature is impossible to measure with standard thermometers. The bullet was a 5.56 mm NATO round (fired from an AR-15 carbine) traveling at about 930 m/sec. We wanted to freeze the apparent motion of the bullet, so we chose the shortest integration time (shutter speed) for this camera, which is 10 µsec.

The bullet travels 9.3 mm in this time, about half of its length. One can see a blurred "tail" to the bullet caused by its motion. The camera has an indium antimonide detector with a cold filter that results in a 3 to 5 µm wavelength sensitivity, and a 50 mm lens that was placed about 1 m from the gun's muzzle.

We set up a digital data acquisition system to record 600 frames of 12-bit digital image data at 60 frames/sec. We would then empty a 30-round magazine through the gun over the 10 sec recording time. We would go back through the sequence frame by frame to find images of the bullet emerging from the muzzle gas cloud. The bullets cooled as they traveled away from the gun. Any bullet within the gas cloud is effectively invisible to this camera.

Once we had located the best image in our data set, we measured the signal level average on the pixels right in the center of the bullet in the image. This signal level was found to be 3,800 digital counts out of a possible 4,096. We then pointed the camera at a high-temperature cavity blackbody source that had a copper penny placed inside of it. The penny has a surface of oxidized copper, and emits MWIR light in a similar manner to a copper-jacketed bullet in flight. When the penny temperature reached 267°C, the signal level averaged over a cluster of pixels within the penny's boundaries was the same as the signal level from the bullet.

This type of calibration is the most accurate way to measure the temperature of an object that is not a perfect blackbody emitter, as is the case with a bullet. We concluded that the bullet's temperature was around 267°C. The bullet gets very hot as it is forced down the rifle barrel at supersonic speeds.

—Austin Richards, PhD

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