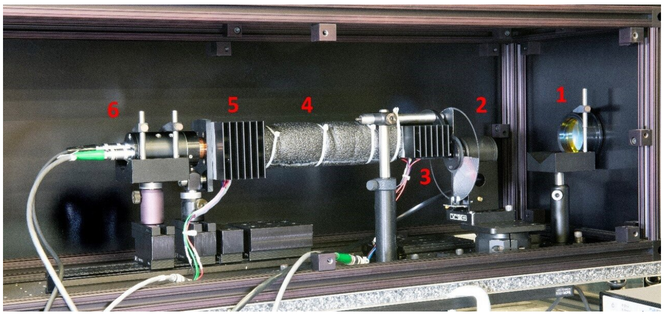
Precise temperature measurements with invisible light

7 May 2019



Operation of the NIST Ambient Radiation Thermometer, which is approximately 60 cm (24 in. long (1) Infrared (IR) light from a fixed-temperature calibrated source (at right, not shown) enters the thermometer enclosure through this lens, which focuses the radiation onto a “field stop,” analogous to the f-stop aperture in photography. (2) A circular metal chopper slices the IR beam into a sequence of pulses. (3) The first lens inside the central cylinder converts the light from the field stop to a parallel beam. (4) The light passes through this insulated cylinder about 30 cm (12 in.) long which is temperature-controlled by a feedback system. Stray radiation is blocked by another stop. (5) A second lens focuses the light onto a pyroelectric detector. (6) The detector output is routed to an amplifier that boosts the signal to readily readable levels. Credit: NIST

Ordinarily, you won't encounter a radiation thermometer until somebody puts one in your ear at the doctor's office or you point one at your forehead when you're feeling feverish. But more sophisticated and highly calibrated, research-grade "non-contact" thermometers – which measure the infrared (heat) radiation given off by objects without touching them – are critically important to many endeavors besides healthcare.

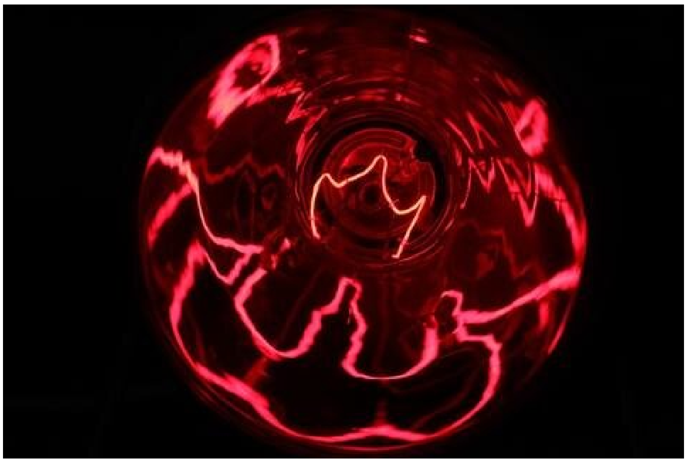
However, even high-end conventional radiation thermometers have produced readings with worryingly large uncertainties. But now researchers at the National Institute of Standards and Technology (NIST) have invented a portable, remarkably stable standards-quality radiation thermometer about 60 cm (24 in.) long that is capable of measuring temperatures to a precision of within a few thousandths of a degree Celsius.

NIST has a long history of studying radiation thermometers. The new prototype instrument, which builds on that work, can measure temperatures between -50 ?C (-58 ?F) to 150 ?C (302 ?F). The corresponding infrared wavelengths are from 8 to 14 micrometers (millionths of a meter), which is a sort of thermodynamic sweet spot.

"All temperatures are equal, but some are more equal than others," said NIST physicist Howard Yoon, who created the thermometer design and directed the project, described in the journal *Optics Express*. "That 200-degree span covers nearly all naturally occurring temperatures on Earth. If you make a big impact in measuring objects in that range, it really matters."

In addition to clinical medicine, temperatures in that region are of urgent importance in applications where contact is not appropriate or feasible. For example, surgeons need to measure the temperature of organs prior to transplant. Modern farmers need accurate temperatures when handling, storing, and processing food. Satellites require non-contact thermometers for measuring temperatures on land and the surface of the sea.

Conventional radiation thermometers often contain little more than a lens for focusing the infrared radiation and a pyroelectric sensor, a device that converts heat energy into an electrical signal. Their measurements can be affected by temperature differences along the thermometer and by temperature outside the instrument.



Infrared lamp. Credit: Bernd Marczak from Berlin from Pixabay

The NIST design, called the Ambient-Radiation Thermometer (ART) is fitted with a suite of interior thermometers that constantly gauge temperatures at different points in the instrument. Those readings are sent to a feedback loop system which keeps the 30 cm (12 inches) cylinder containing the detector assembly at a constant temperature of 23 ?C (72 ?F).

It also features other design improvements, including a method for reducing errors from what is called the size-of-source effect, which results when radiation enters the instrument from areas outside its specified field of view.

The ART's major advantage is its unprecedented stability. After it has been calibrated against standards-grade contact thermometers, the instrument can remain stable to within a few thousandths of a degree for months under continuous operation. That makes the system very promising for applications that involve remote sensing over long periods.

"Imagine being able to take the NIST design out in the field as traveling radiation thermometers for accurately measuring variables such as land- and sea-surface temperatures," Yoon said. "It could serve as a trustworthy method of calibrating satellite IR sensors and validating the huge weather science programs that are used to predict, for example, the paths and strengths of hurricanes." Its lower range of -50 ?C (-58 ?F) makes it suitable for monitoring the temperature of ice over polar regions, typically in the range of -40 ?C (-40 ?F) to -10 ?C (14 ?F).

There are several methods of making very high-accuracy temperature measurements, but few are well-suited to field work. Platinum resistance thermometers are fragile and need frequent re-calibration. The standard temperature source for transferring that calibration to the ART involves a heat-source cavity inside about 42 liters (11 gallons) of liquid.

"Those are the best sources we have," Yoon said. "But it is impractical to measure water temperature by putting a thermometer in the ocean at intervals, and you don't want to constantly calibrate your radiation thermometer using a calibration source like that onboard a ship."

Gerald Fraser, chief of NIST's Sensor Science Division, said that "Yoon's innovation makes non-contact thermometry competitive with the best commercial contact thermometers in accuracy and stability in a temperature range that humans experience daily. This enables many new opportunities in product inspection and quality control and in defense and security where conventional contact methods are impractical or too expensive."

More information: Howard W. Yoon et al. Improvements in the design of thermal-infrared radiation thermometers and sensors, *Optics Express* (2019). DOI: 10.1364/OE.27.014246

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Provided by National Institute of Standards and Technology

APA citation: Precise temperature measurements with invisible light (2019, May 7) retrieved 18 November 2019 from https://phys.org/news/2019-05-precise-temperature-invisible.html