# Evaluation of an Infrared Distance-Measuring Sensor

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July 7, 2014

**U.S. CONSUMER PRODUCT SAFETY COMMISSION**
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# 1. Introduction

Fires associated with the use of electric heaters continue to be one of the leading contributors to total fires in residences. According to the U.S. Consumer Product Safety Commission (CPSC) report, *2009–2011 Residential Fire Loss Estimates*,[1] fixed-position and portable electric heaters were associated with an annual average of 3,500 fires, 60 deaths, 340 injuries, and $116.8 million in property damage.

Using a different analysis method than that used by CPSC, the National Fire Protection Association (NFPA) estimated that electric-powered space heaters (fixed-position or portable) were associated with an annual average of 9,680 fires, 172 deaths, 742 injuries, and $248 million in property losses.[2] The NFPA report lists: "Heat source too close to combustibles," as the leading factor contributing to ignition for electric space heater fires, in an estimated 28 percent of the fire incidents. The presence of combustibles provides the fuel and the potential to initiate a fire.

Recently enacted amendments to the Underwriters Laboratories (UL) voluntary standards UL 1278, *Movable and Wall- or Ceiling-Hung Electric Room Heaters*, and UL 2021, *Fixed and Location-Dedicated Electric Room Heaters*, require manual-reset temperature-limiting controls (in place of auto-reset controls) for many heater types.[3] Although these changes are expected to address some factors contributing to fires initiated inside electric heaters, overheating of combustibles outside the heater is less likely to activate the temperature-limiting control. UL 1278 and UL 2021 do not contain any performance requirements for heaters to detect nearby combustibles. The CPSC and the NFPA advise consumers to keep combustible materials at least 3 feet away from electric heaters.[4] If potential combustibles located near an electric heater could be sensed, it is possible that the heater could respond automatically to that condition by shutting off or reducing its heat output (and, perhaps, activating an alarm to alert nearby persons), reducing the probability of a fire incident.

Some manufacturers have installed sensing devices, such as motion detectors, to deenergize the heater if an object moves too close to the front of the appliance. In 2013, CPSC staff evaluated the use of a long-wavelength infrared (IR) radiation sensor installed on a radiant

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[1] See http://www.cpsc.gov/Global/Research-and-Statistics/Injury-Statistics/Fuel-Lighters-and-Fireworks/2009-2011ResidentialFireLossEstimatesFinal.pdf.

[2] See http://www.nfpa.org/~/media/Files/Research/NFPA%20reports/Major%20Causes/osheating.pdf. This average was calculated over the years 2007−2011.

[3] A temperature-limiting control disconnects electric power from the heating elements when an internal temperature threshold is reached. Auto-reset controls automatically reconnect electric power to the heating elements when the heater's internal temperature drops a certain amount. Manual-reset controls require user interaction, such as unplugging the heater for 5 minutes to restore functionality.

[4] CPSC: http://www.cpsc.gov//Global/Safety%20Education/Home-Appliances-Maintenance-Structure/098.pdf , NFPA: Ibid, page 39.

electric heater to detect objects placed too close to the heater.[5] In that evaluation, the reflected long-wavelength IR emission from the heated surface in front of the heater was detected by the sensor.

This study evaluates a short-wavelength IR emitter/detector sensor for its ability to detect objects of different reflectances at distances up to 3 feet from the sensor. Because the sensor includes an IR emitter, sensor applications in electric heaters conceivably could include radiant, forced-air and natural convection models. The application of proximity sensing (using a sensor to detect objects at specific distances from the sensor), has the potential to reduce the number of fire incidents where "combustibles too close" is a contributing factor.

## 2. Sensor characteristics

The sensor chosen for this evaluation includes a short-wavelength IR emitter with a nominal output wavelength centered around 850 nanometers.[6] The sensor also includes a detector that senses the reflection of the emitted radiation off of an object placed in front of the sensor. The emitter discharges IR pulses, which are reflected by an object into the detector.

This particular sensor model is a rangefinder that outputs a voltage proportional to the distance between the sensor and the object in front of it. The published measuring range of this sensor is 80 cm (31.5 inches). This model was chosen for its ready availability, simple analog voltage output, and its range, which is close to the 3-foot clearance recommended for electric heaters. Figure 1 shows a picture of the sensor mounted on a post.

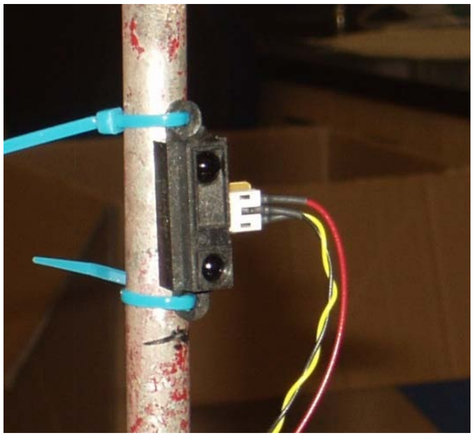

**Figure 1: Infrared Sensor (or Infrared Emitter/Detector)**

[5] http://www.cpsc.gov/Global/Research-and-Statistics/Injury-Statistics/Home%20Maintenance%20and%20Construction/ProximityDetectorCircuit.pdf.

[6] Visible light is typically described as light with wavelengths between 400 and 700 nanometers. Thus, 850 nanometers is just beyond the red portion of the visible light spectrum. The manufacture and use of IR emitters and detectors is a well-established technology.

There is a wide selection of short-wavelength IR emitter/detectors available that may be matched with a particular heater design to optimize system performance. Manufacturers have a range of sensor design features available for their use.

The sensor used in this evaluation is insensitive to other sources of light, such as incandescent or fluorescent lamps, or reflections. However, like most optical sensors, if a strong light source is oriented directly into the detector, there is the possibility of saturating the input and rendering the sensor ineffective.

The sensor body is about 1.2 inches long and 0.5 inches wide. The emitter and detector are spaced 0.79 inches (20 mm) apart, nominally. For this sensor, the detection zone is shaped effectively like a constant-width beam, rather than an expanding cone. When oriented vertically, the detection zone of this sensor is narrow, about 0.5 to 1.0 inch wide at a 15-inch distance. When mounted horizontally, the detection width is about 2 inches.

## 3. Experimental Setup

Because the sensor does not depend upon any characteristic of a heater, such as radiant emission, mounting the sensor onto a heater was not necessary to characterize its performance. A simple metal stand was used to mount the sensor approximately 11 inches above the laboratory tabletop. The sensor operates on 5 volts dc and is specified to consume a maximum of 50 milliamperes of current. The output of the sensor was filtered with a single pole RC filter[7] to reduce the high-frequency voltage spikes observed as the sensor resampled the distance to the target.

The narrow detection width of the sensor allows any size reflective target, larger than the detection width, to be used in the measurements. A handy cardboard box was employed as a frame on which cloths of different reflectances could be attached. Five different cloths were used in the testing: white, light grey, medium grey, dark grey, and black. The various colors were chosen to evaluate the sensor's sensitivity with varying distance, and how the output may change as a function of target reflectance.[8] Each cloth was taped flat to the target face of the box, with a thickness of four layers of cloth, to ensure that the color and reflectance of the cardboard box had no effect on the distance measurements. The box was large enough, and the cloths were uniform in color, so that precise positioning perpendicular to the face of the sensor was unnecessary.

Because the sensor was wired to a small circuit and attached to the dc power supply, moving the cloth-covered box relative to the stationary sensor during testing was more convenient. A tape measure was attached to the table to indicate the distance from the box to the sensor. The

[7] The selection of the corner frequency of the filter is noncritical to the DC voltage output. A 27 KΩ resistor was paired with 3.31 μF of capacitance to create a low-pass filter with a corner frequency of 1.8 Hertz.

[8] The actual reflectance in the near IR of these cloths is unknown, but the emitter wavelength is just beyond the visible range, and darker cloths absorb more long wavelength IR, implying that they are "darker" at those wavelengths.

measurements were recorded for sensor-target distances from 3 inches to 36 inches at 1-inch increments. Measurements were recorded with the box at rest. Additionally, the sensor output with no target in front (the equivalent of a target at infinity) was recorded. For each cloth, the measurement set was run twice.

Output voltage measurements were made with a digital voltmeter, and monitored with an oscilloscope. The oscilloscope was useful to observe the instantaneous output of the detector for electrical noise. Figure 2 shows a picture of the experimental setup, with the voltmeter and oscilloscope.

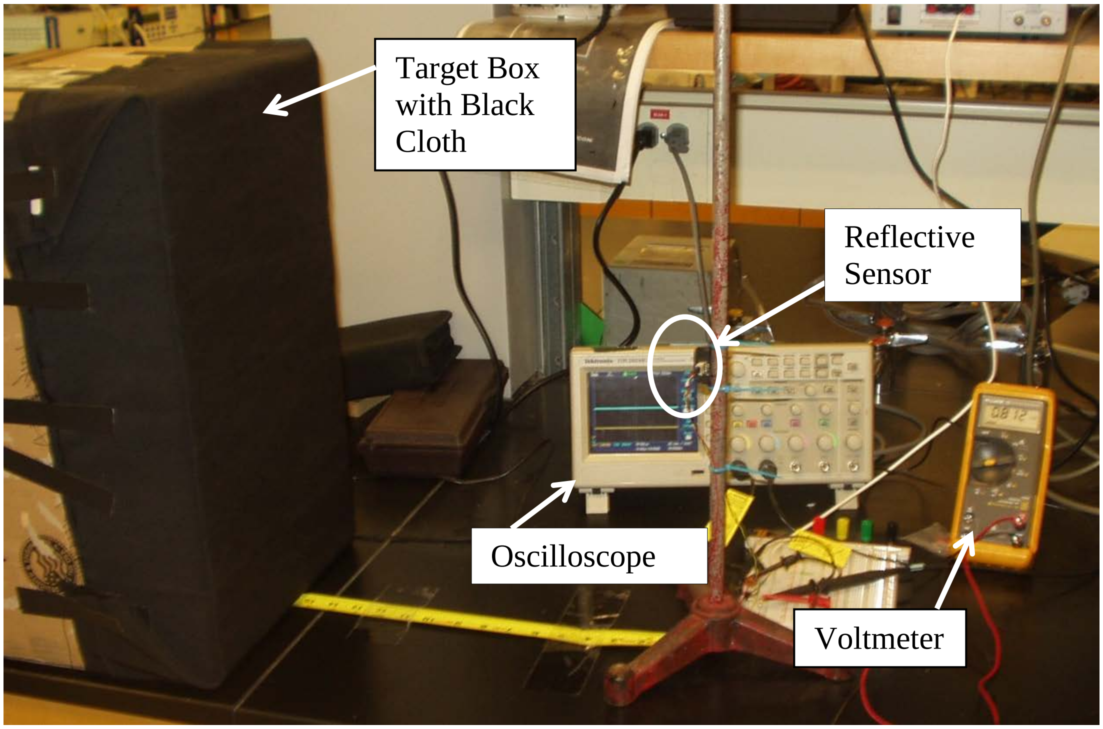


**Figure 2: Experimental Setup**

## 4. Results

At each distance, the sensor repeatedly output the same voltage for the target, regardless of which color cloth was on the box. Figure 3 shows a chart of sensor output voltage versus target box distance from the sensor. For all practical purposes, output voltage plots for each different cloth produced the same results. The lines at the bottom of the chart show a consistent 28 mV signal for the absence of a target (*i.e.*, a target at infinity).

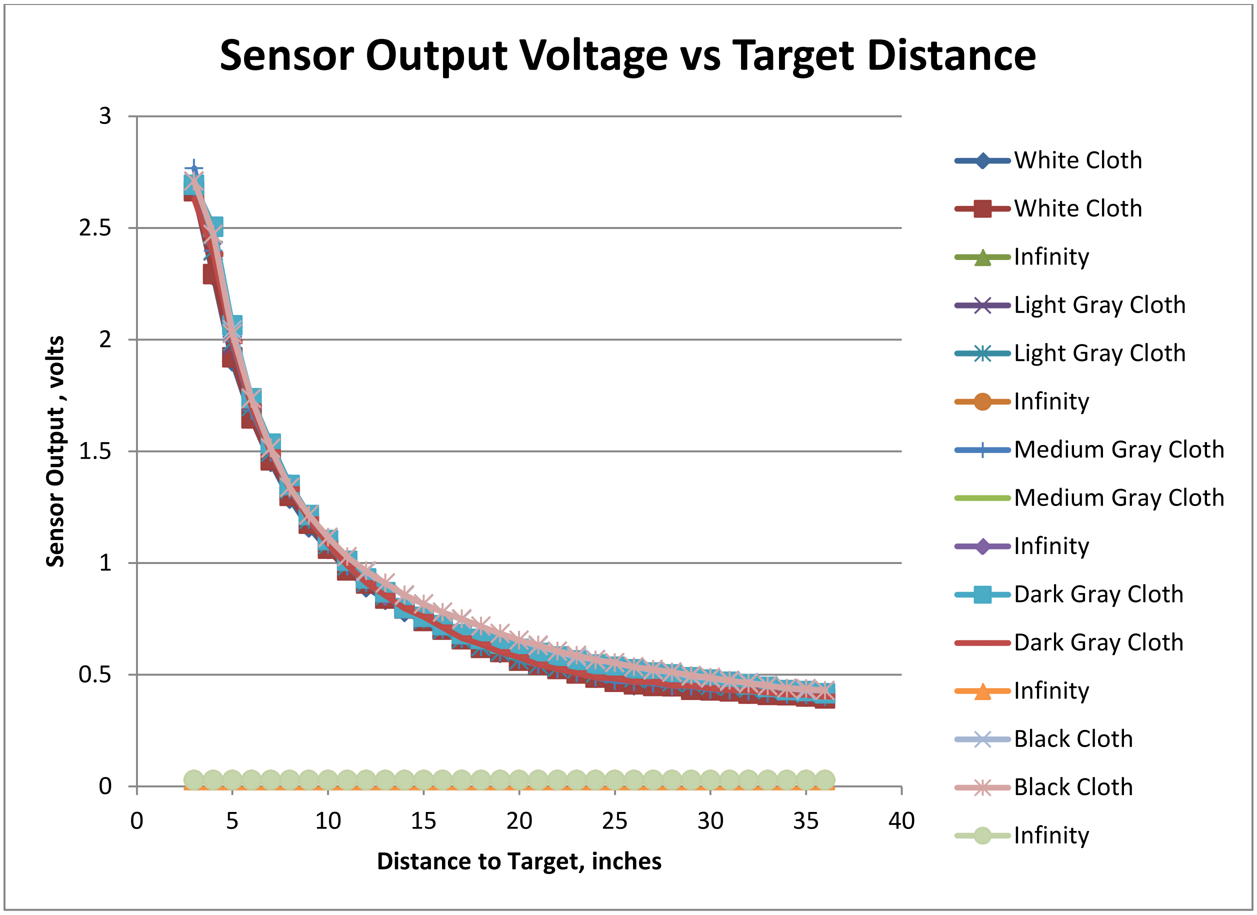


**Figure 3: Experimental Results**

As indicated in the sensor specifications, the relationship between output voltage and distance is nonlinear. Fitting the average of all the target box readings with a power series mathematical expression results in the equation shown in (1):

$$\text{Distance (in.)} = 6.92 * \text{Voltage}^{-0.805} \tag{1}$$

The coefficient of determination, $R^2$, which indicates how well the power series expression statistically fits the averaged readings, is equal to 0.996, indicating a very strong fit. Figure 4 shows a plot of the average of the readings and the power series curve fit.

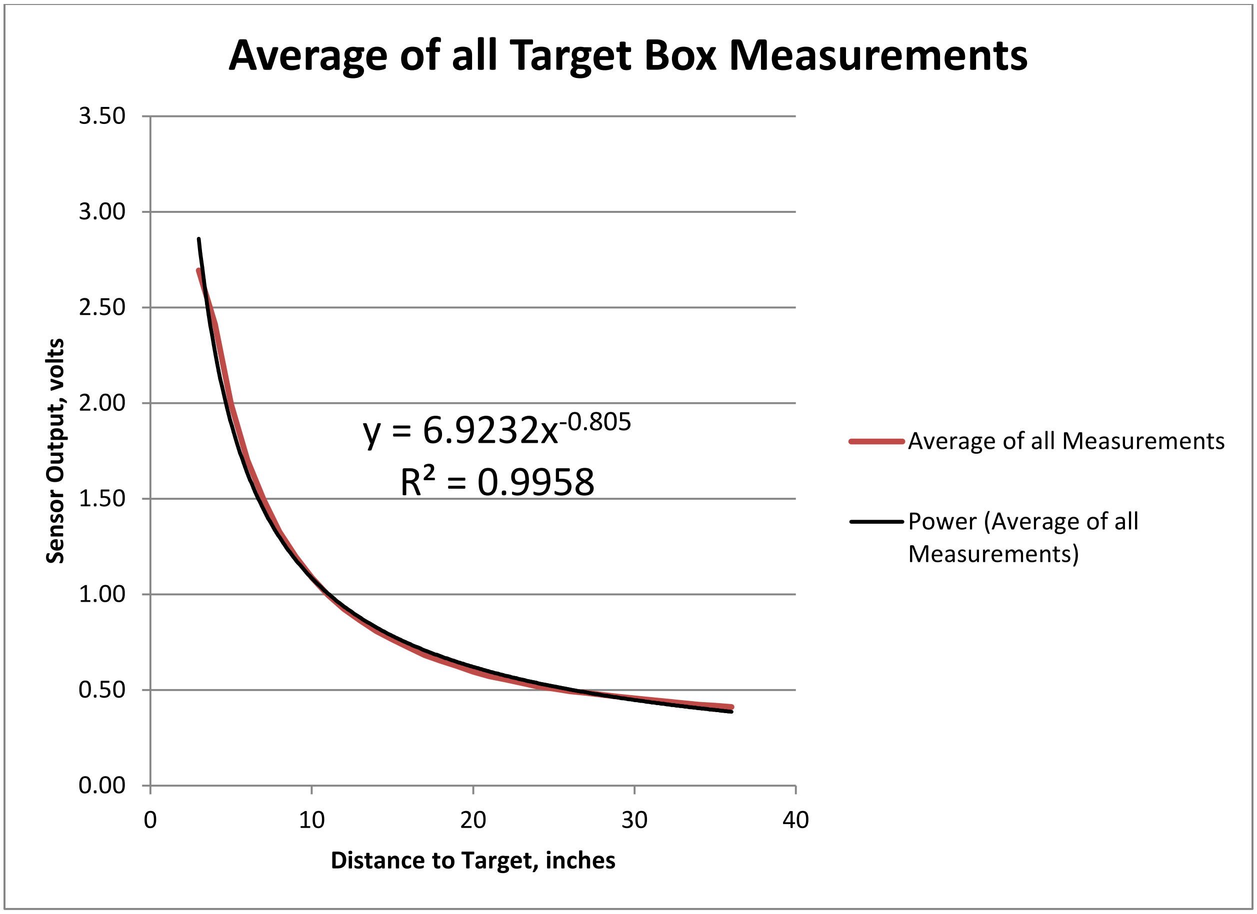


**Figure 4: Average Sensor Response and Power Series Curve Fit**

During the initial testing with no target, the sensor signal was observed to vary between 0.50 and 0.53 volts. This value was higher than some readings recorded at long distances. When the sensor was rotated 180 degrees, to reverse the vertical positions of the emitter and detector, the signal vanished. Subsequent measurement in varying sensor positions failed to restore the stray sensor signal with no target present.

Further measurements with the sensor mounted horizontally, showed consistent performance, regardless of target reflectance or sensor orientation. A second sensor showed similar performance, regardless of target reflectance or sensor orientation, with 20 mV (three percent of the signal value) as the largest measurement difference for the two sensors at any distance.

At a fixed distance of 15 inches, different colored cloths (green, orange, blue, purple, and yellow) were draped over the target box. The sensor output was found to be insensitive to the color of the draped cloth. Additionally, the target box was tilted so that the front surface was no longer perpendicular to the sensor face. The sensor output was found to be insensitive to the tilt of the target. Sensor performance was not evaluated for targets with complicated geometries, like sharp edges or curved surfaces. The minimum target size that could be detected at a given distance was not determined.

To evaluate the sensor's sensitivity to external infrared radiation sources, a radiant electric heater was used to heat the target by placing the heater near the target and directing the infrared emission onto the cloth (black cloth was used for this test to absorb more of the heater's output). The energized heater was left in place until the cloth was uncomfortably warm to the touch. No change in the sensor output was detected as a function of the cloth temperature. The target box was replaced by the radiant electric heater whose output was directed at the sensor. The heater was energized and allowed to reach steady-state conditions. No change was observed in the sensor output.

This sensor is sensitive to specular reflections from its emitter. When a shiny metal surface was placed in front of the sensor, the sensor output could be varied over a wide range, by tilting the surface, in essence, redirecting the specular reflection into the detector, or reflecting almost all of the emitter's energy away from the detector. When a small mirror was placed in front of the sensor at a distance of 15 inches, larger sensor output voltage changes were possible, depending on the tilt of the mirror. Specular reflectance directed into the sensor results in an output indicating that the target is nearer than it is. Specular reflectance directed away from the sensor results in a sensor output indicating that the target is farther from the sensor than it is.

The maximum detection distance for the sensor was approximated by positioning the target box very far from the sensor and observing the sensor output voltage of 28 mV, typical for no target present. The target was slowly moved toward the sensor until the sensor output was approximately 10 times the "infinity" value. This change occurred with the target box about 8 feet from the sensor. Thus, the sensor appears able to detect objects beyond its published sensing distance of 80 cm (2.6 feet).

## 5. Discussion

An off-the-shelf, readily available sensor was shown to be capable of detecting a target at distances up to 3 feet. The sensor output was consistent, regardless of the color of the target, its orientation, or its temperature, showing an insensitivity to target reflectance for non-shiny surfaces.

If considered as a proximity sensor for electric heater applications, the following design criteria could be considered:

- Area of coverage: This sensor has a narrow detection width. Depending on a heater's shape, one or more sensors of this type may be required to cover the full heating surface area. Alternatively, research could be conducted on developing wide-angle detector circuits.

- Position: Although safety literature states that combustibles are to be kept 3 feet away from all sides of a heater, proximity sensing might reasonably be limited to the front of a heater. This face is where the heated air or radiant emission enters the room, and may be more likely to be associated with fire incidents.

- Orientation: Although the sensor is insensitive to ambient illumination, a strong light source directed into the detector has the potential to saturate the sensor and render the sensor ineffective. Additionally, if two heaters with the same sensor model were to face each other, there is a possibility that the emitter output of one sensor could be detected by the other sensor.

- Electrical interface: This sensor has a simple analog output. Because the output signal is consistent for many reflectance values, the simplest interface could be a level-detecting switch; if the output voltage is above about 0.4 volts (corresponding to an object at a three foot distance), the heating elements could be deenergized. More sophisticated circuitry could take intermittent proximity into account, such as an object or person passing in front of the heater. Intermittent proximity is less likely to pose a fire hazard.

- Potential interference: The source of the small offset seen in early testing was never identified. Furthermore, very shiny surfaces near the sensor have the potential to disrupt sensor performance.

- Applicability: A proximity sensor would be a safety device that needs to function properly under multiple operating conditions and for many potential heater applications. Design consideration should be given to foreseeable use and misuse circumstances.

"Combustibles too close" is a phrase associated with many fire incidents attributed to electric heaters. As sensing technologies advance, means to detect objects in front of an electric heater become more practical to implement. A readily available infrared reflective sensor is capable of such detection, within limits. While not the only means by which a proximity sensing function could be implemented on an electric heater, this evaluation has highlighted the promise and potential issues of IR object detection.