Measurement of Wood's Emissivity Using Infrared Thermometry

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This study investigates the emissivity of a wooden surface using an MLX90614 infrared sensor and a thermocouple for calibration. A controlled heating process was implemented, where temperature readings were recorded for both the wood sample and the surrounding environment. The experiment was conducted in two phases: initially, with the MLX90614 sensor set to an emissivity of 0.95 for baseline calibration, and subsequently, with an adjusted emissivity to refine measurement accuracy. A comparative analysis between infrared and thermocouple readings was performed to establish a reliable emissivity value. The findings contribute to improving infrared sensor calibration techniques for emissivity estimation of organic materials.
Keywords: Emissivity, infrared thermometry, thermal radiation, calibration.

I. INTRODUCTION

Emissivity is a critical parameter in thermal radiation studies, representing a material's efficiency in emitting infrared energy compared to an ideal blackbody. Accurate emissivity determination is essential for various applications, including industrial monitoring, environmental studies, and remote sensing. Infrared thermometry offers a non-contact approach to temperature measurement, making it a valuable tool for analyzing materials with sensitive or inaccessible surfaces. However, the precision of infrared temperature readings depends significantly on correct emissivity calibration, as material-specific variations can introduce significant errors.

Wood, as a heterogeneous and organic material, poses challenges in emissivity estimation due to its variable surface characteristics and composition. While literature provides approximate emissivity values for wood, direct experimental validation is necessary to improve calibration accuracy.

This study presents an experimental approach to determine the emissivity of wood by comparing infrared sensor readings with direct-contact thermocouple measurements.

II. EXPERIMENTAL DETAILS

A. Experimental Procedure

The setup shown in Figure 1 was designed to determine the emissivity of wood, this setup incorporates an MLX90614 infrared sensor. A heater was used to induce a controlled temperature increase in the sample, while temperature readings were simultaneously recorded for both the wood surface and the surrounding environment. The experiment consisted of two primary measurement phases:

Baseline Calibration: The MLX90614 infrared sensor was initially set to an emissivity of 0.95, providing a reference for infrared readings.

Refined Measurement: The emissivity setting was then adjusted to enhance accuracy, ensuring better agreement with thermocouple readings.

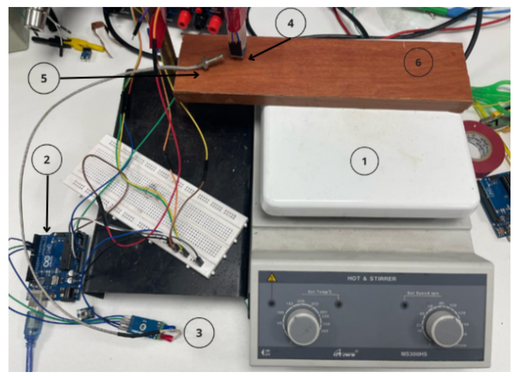

FIG. 1. The photograph of the sample holder for the emissivity measurement. 1 Heater; 2 Arduino; 3 MAX6675 modulus; 4 MLX90614 infrared sensor; 5 thermocouple; 6 grey body.

During data collection, infrared temperature readings were compared against thermocouple measurements, with particular attention given to minimizing environmental influences. The relationship between the two datasets was analyzed using scatter plots to assess the correlation between contact and non-contact measurement techniques.

B. Mathemathical Model

To determine the emissivity of wood, the experiment followed a mathematical model based on the Stefan-Boltzmann law, which describes the amount of radiation emitted by a black body at temperature T across all wavelengths:

$$L(T) = \frac{\sigma}{\pi} T^4 \tag{1}$$

where $\sigma \approx 5.670373 \times 10^{-8}\ [W m^{-2} K^{-4}]$ is the Stefan-Boltzmann constant, and L is the radiation density of the object. This law was used alongside Kirchhoff's law of thermal radiation:

$$\epsilon(\lambda) = \alpha(\lambda) \tag{2}$$

which reveals the relation between the emissivity ϵ and absortion α of a body.

It is important to note that the MLX90614 IR sensor operates within a specific wavelength range. Consequently, the measured radiation density does not account for components beyond the infrared range specified in the sensor's datasheet. Thus, applying equation (1) provides only an approximation of the actual radiation density L.

To ensure an accurate measurement of the sample's radiation, the net radiation L_{net} recorded by the MLX90614 IR sensor was characterized as follows

$$L_{net} = L_{obj} + L_{ref} + L_{atm} \tag{3}$$

This equation states that the net radiation is the sum of the radiation emmited by the object, the reflection of ambient and the atmospheric radiation.

By neglecting atmospheric radiation and defining the object's radiation and reflection as:

$$L_{obj} = \epsilon_1 L_g$$
$$L_{ref} = r_1 L_{amb}$$

where ϵ_1 is the emissivity of the object, r_1 is it's reflection factor, and L_g the radiation of the object as if it were a black object. Since, r is related to the emissivity by $r = 1 - \epsilon$, the net radiation can be expressed as:

$$L_{net} = \epsilon_1 L_g + (1 - \epsilon_1) L_{amb} \tag{4}$$

A further consideration must be made to improve the reliability of the data collected. The MLX90614 IR sensor is not a perfect black body, and unaccounted systematic factors may affect the total absorption of L_{net}. This issue can be addressed by introducing an *efective absortion factor* c_0, such that the measured radiation is:

$$L_{sensor} = c_0 L_{net} = c_0(\epsilon_1 L_g + (1 - \epsilon_1) L_{amb})$$

Therefore, using eq.(1) and moving c_0, σ with L_{sensor}

$$\frac{L_{sensor}}{c_0 \sigma} = \epsilon_1 T_{obj}^4 + (1 - \epsilon_1) T_{amb}^4 \tag{5}$$

Solving for ϵ_1, we get:

$$\epsilon_1 = \frac{T_{amb}^4 - \frac{L_{sensor}}{c_0 \sigma}}{T_{amb}^4 - T_{obj}^4}$$

Since c_0 is unknown, a calibration process should be performed. To do so, consider two emissivities, ϵ_1 (the real which, still undetermined) and ϵ_2 (a calibration parameter), Therefore, using eq.(5), and relating them to the temperature measured by the thermocouple and the MLX90614 IR sensor respectively, we obtain:

$$\frac{L_{sensor}}{c_0 \sigma} = \epsilon_1 T_{tcouple}^4 + (1 - \epsilon_1) T_{amb}^4$$
$$\frac{L_{sensor}}{c_0 \sigma} = \epsilon_2 T_{obj}^4 + (1 - \epsilon_2) T_{amb}^4$$

Finally, assuming L_{sensor} and c_0 remain constant throughout the experiment, equating the expressions leads to

$$\epsilon_1 = \epsilon_2 \frac{T_{obj}^4 - T_{amb}^4}{T_{tcouple}^4 - T_{amb}^4} \tag{6}$$

which is the formula used to determine the data presented in section III.

(Note: Both T_{obj} and $T_{tcouple}$ represent the object's temperature. However, T_{obj} is measured by the MLX90614 IR sensor, providing direct data from the object's radiation. If this temperature were recorded exclusively by a thermocouple, the emissivity determination would rely entirely on the mathematical model. Therefore, these two values should closely match in the measurements.)

III. RESULTS AND DISCUSSION

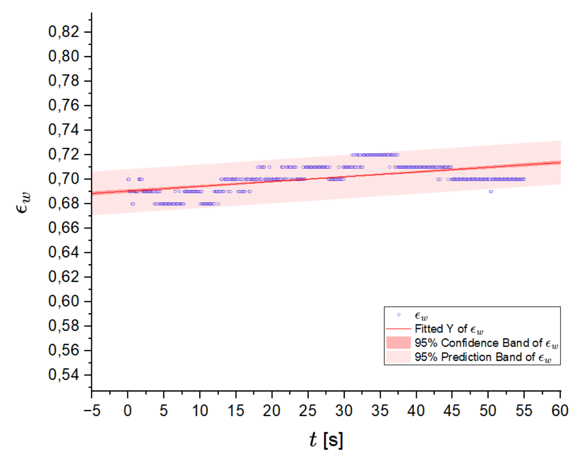

FIG. 2. Measurements and linear fitting of ϵ_w vs t for a 60 s period time.

As mentioned in section II B, the emissivity of the wood sample, ϵ_w, was determined after a calibration process, yielding a calibration parameter of $\epsilon_2 = 0.95$.

The emissivity measurements over 60 seconds using this calibration parameter are shown in FIG. 2. Ideally, the emissivity should remain constant over time. However, the low linear correlation ($R^2 = 0.317$) suggests systematic errors. The primary sources of error are: (1)

instrument limitations, such as the thermocouple's resolution of 0.25 $[K]$, and (2) the model's approximation, which assumes that $L(T)$ accounts for all wavelengths, while the MLX90614 IR sensor only records a specific infrared band.

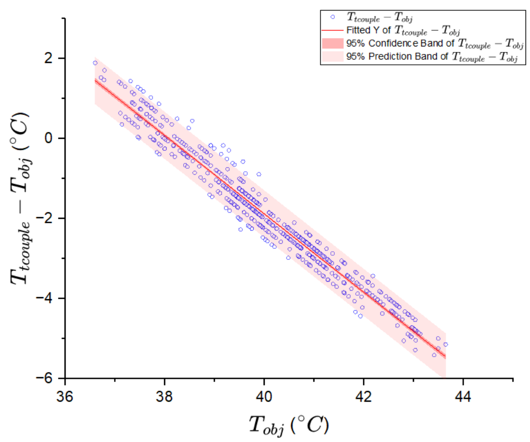

FIG. 3. Measurements and linear fitting of the differences of temperature $T_{tcouple} - T_{obj}$ vs T_{obj} for a 60 s period time.

Additional insights into errors can be gained by noting that T_{obj} acts as the primary source of errors stemming from the assumptions of the mathematical model, as its values are limited to the specific infrared band detected by the MLX90614 sensor. The trend of these errors is illustrated in FIG. 3 which provides a clearer perspective by revealing a strong linear correlation ($R^2 = 0.96$) with T_{obj}. This correlation indicates that measurement discrepancies increase as T_{obj} deviates from 38°.

To minimize errors, a weighted mean was applied using the temperature differences $\Delta T_i = |T_{tcouple,i} - T_{obj,i}|$, where weights were defined as:

$$w_i = \frac{1}{\Delta T_i + \epsilon}$$

where $\epsilon = 10^{-6}$ is value to prevent division by zero. This approach ensures that measurements with smaller errors contribute more to the final result.

The weighted mean, considering standard error and instrument uncertainty, yielded an experimental emissivity of:

$$\epsilon_w = 0.689 \pm 0.164$$

Comparing this to the literature values that report varying emissivities of $\epsilon_w = 0.855 - 0.920$ Cu at 40°C [1], the result is reasonable, considering the experiment's highest reliability was at approximately 38°C. Additionally, the presence of a thin resin layer on the wood sample could have influenced the measurement.

IV. CONCLUSION

The experiment aimed to determine the emissivity of a wood sample using a mathematical model derived from the Stefan-Boltzmann law and Kirchhoff's law of thermal radiation. The analysis showed that the measured emissivity values deviated from the expected constant behavior, with an R^2 value of 0.317, suggesting the presence of systematic errors.

Two primary sources of error were identified: (1) limitations in the measuring instruments, particularly the thermocouple's resolution of 0.25 $[K]$, and (2) the approximation inherent in the mathematical model, as the MLX90614 IR sensor only detects radiation within a specific infrared range rather than the full spectrum considered in the Stefan-Boltzmann equation. Further analysis of temperature discrepancies between the MLX90614 IR sensor and the thermocouple revealed a strong correlation ($R^2 = 0.96$) between the measurement errors and the object's temperature, indicating that the sensor's readings became less accurate as the temperature deviated from 38°C.

To mitigate measurement errors, a weighted mean approach was employed, prioritizing data points with smaller temperature discrepancies. The resulting experimental emissivity was determined to be $\epsilon_w = 0.689 \pm 0.164$, which, while lower than the literature values, remains reasonable given the conditions of the experiment. The presence of a resin layer on the wood sample could have influenced the emissivity measurement, further contributing to the deviation.

Future improvements to this methodology could involve using sensors with a broader spectral range, refining calibration procedures, and conducting additional tests with different wood samples to better assess variability. Despite the observed deviations, the study provides a useful empirical approach to estimating emissivity and highlights the importance of considering sensor limitations in thermal radiation measurements.

[1] G. López, L. Basterra, L. Acuña, and M. Casado, Determination of the emissivity of wood for inspection by infrared thermography, Journal of Nondestructive Evaluation **32** (2013).

[2] Maker Portal, Infrared thermometry theory and applications with arduino and python (2019), accessed: 2025-03-15.