Surface Temperature Measurement Using Color-Band Method

Elvin Ip, Hong Lu, Justin Scott, and Larry Baxter

ACERC, Chemical Engineering Department, Brigham Young University, Provo, Utah

Objective

A new color-band method for surface temperature measurement with imaging cameras (CCD/CMOS)

Algorithms

Planck's law:

$$I_\lambda(\lambda,T)=\frac{\frac{h\cdot c_o}{k}}{\lambda^5\cdot\left[\exp\left(\frac{2\pi\cdot h\cdot c_o^{\,2}}{\lambda\cdot T}\right)-1\right]}$$

Single-color-band method:

$$DN=\frac{\pi}{4}\cdot\left(\frac{D}{d}\right)^2\cdot\frac{a^2}{X}\cdot\Delta t\cdot\int_{\lambda_1}^{\lambda_2}S(\lambda)\cdot\frac{\frac{h\cdot c_o}{k}}{\lambda^5\cdot\left[\exp\left(\frac{2\pi\cdot h\cdot c_o^{\,2}}{\lambda\cdot T}\right)-1\right]}\cdot d\lambda$$

Multi-color-band method:

$$\frac{DN_{Red}}{DN_{Blue}}=\frac{\int_{\lambda_1}^{\lambda_2}\frac{S(\lambda_{Red})}{\lambda_{Red}^{\,5}\cdot\left[\exp\left(\frac{2\pi\cdot h\cdot c_o^{\,2}}{\lambda_{Red}\cdot T}\right)-1\right]}\cdot d\lambda}{\int_{\lambda_1}^{\lambda_2}\frac{S(\lambda_{Blue})}{\lambda_{Blue}^{\,5}\cdot\left[\exp\left(\frac{2\pi\cdot h\cdot c_o^{\,2}}{\lambda_{Blue}\cdot T}\right)-1\right]}\cdot d\lambda}$$

Single-color-band method with furnace wall radiation consideration: (Thermal Radiation)

$$DN=\frac{\pi}{4}\cdot\left(\frac{D}{d}\right)^2\cdot\frac{a^2}{X}\cdot\Delta t\cdot\int_{\lambda_1}^{\lambda_2}S(\lambda)\cdot\frac{\frac{\left[1-(1-\varepsilon_1)\cdot F_{2\_2}\right]\cdot\varepsilon_1\cdot\frac{h\cdot c_o}{k}}{\lambda^5\cdot\left[\exp\left(\frac{2\pi\cdot h\cdot c_o^{\,2}}{\lambda\cdot T}\right)-1\right]}+\frac{(1-\varepsilon_1)\cdot\varepsilon_2\cdot\frac{h\cdot c_o}{k}}{\lambda^5\cdot\left[\exp\left(\frac{2\pi\cdot h\cdot c_o^{\,2}}{\lambda\cdot T}\right)-1\right]}}{\left[1-(1-\varepsilon_2)\cdot F_{2\_2}\right]-\left[(1-\varepsilon_1)\cdot(1-\varepsilon_2)\cdot F_{2\_1}\right]}\cdot d\lambda$$

where: $F_{2\_1}=\frac{A_1}{A_2}$ $\quad F_{2\_2}=1-\frac{A_1}{A_2}$

Nomenclatures:

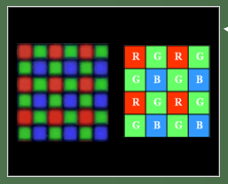
I --- Spectral intensity
λ --- Wavelength
T --- Object temperature
h --- Planck's constant
k --- Boltzmann constant
c_o --- Speed of light

DN --- Pixel count
d --- Lens working distance
D --- Lens diameter
a --- Pixel area
T --- Transmission factor
X --- Magnification
Δt --- Exposure time
S --- Spectral response function

ε --- Emissivity
A_1 --- Object surface area
A_2 --- Furnace wall area
F --- Geometric configuration factor

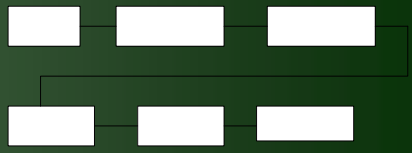
Approach

Calculation is based on the two-color method with integration of the whole visible spectrum. No filters and effective wavelengths are needed. The assumption of gray-body behavior was used.

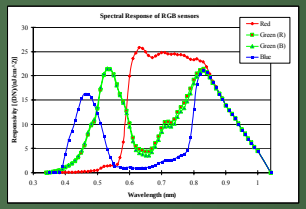


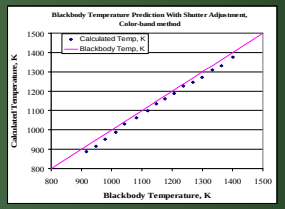
CCD and CMOS sensor color pattern

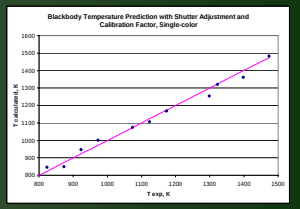
A block diagram of the method



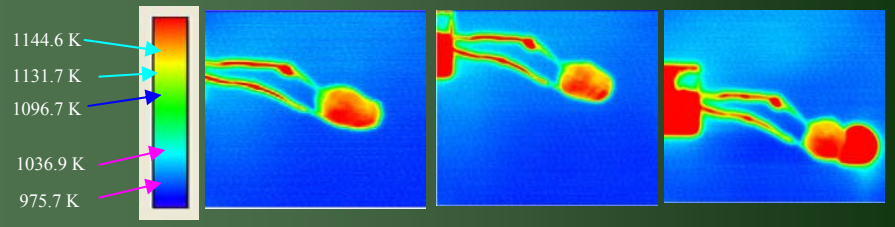
Results







Predicted of a burring black liquor droplet in a 700 °C furnace with single-color method with furnace wall radiation consideration. Emissivity of 0.75 and calibration factor of 5.64 were used.



Conclusion

Imaging cameras were tested for pixel by pixel pyrometry. Integration of the whole visible spectrum was proved to be applicable. The blackbody temperature predictions with color-band and single-color methods were within close range with the thermocouple readings. Single-color method was applied to a burning black liquor droplet in a hot furnace, and the predictions were reliable.

Acknowledgement

This project is sponsored by US DOE/EE Office of Industrial Technologies & Sandia National Laboratories