LARS Information Note: 022571

Calibration of Thermal Channels of the University of Michigan Scanner

by

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Introduction

The 8-13.5 μm and 4.5-5.5 μm channels of the University of Michigan Scanner are responsive to energy in the emissive region of the electromagnetic spectrum. If a target has emissive characteristics close to that of a black-body, it is possible to infer the thermometric temperature of the target from the radiation emitted. Such a procedure is made possible by two temperature reference plates which are extended into the field of view of the scanner. This process of relating the radiation from a target to its thermometric temperature is referred to as calibration. The remainder of this paper will be devoted to a discussion of the calibration procedure developed at LARS.

In nature, a common substance with emissive characteristics close to that of a black-body is water. Thus, an obvious advantage of calibrated data is that it allows one to determine remotely the thermometric temperature of water. There are some real, but generally surmountable, complications to such a procedure. The most important is the effect of the atmosphere between the target and the radiometer. A second is the small departure of the emissive character of water from that of a black-body.

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Aside from making possible remote determinations of water temperatures, calibration of thermal data also removes long term electronic and detector drift. There may also be an advantage to the researcher in relating the "apparent" temperature of land scenes to a thermometric scale. The investigator realizes, however, that because of emissivities distinctly different from "one" these temperatures may depart considerably from the actual thermometric temperatures.

University of Michigan Scanner - Reference Black-bodies

The University of Michigan Scanner has been assembled by combining readily available airborne scanners into a single unit. The final configuration is essentially two dual-channel scanners. Scanner I records energy in the near and far infrared; it has two channels which are of interest in temperature sensing. These are filtered to record energy in the 4.5-5.5 μm and 8.0-13.5 μm wavelength bands.

As it was originally designed, Scanner I did not include a temperature reference. During modification, temperature references were added consisting of two temperature-controlled plates extending into the field of view (FOV) of Scanner I (Figure 1). The normal FOV of the scanner is 80°; with the plates, however, the external FOV is only 34°.

Temperature Reference Sources: The temperature reference sources consist of two $\frac{1}{4}$-inch copper plates which have been grooved and painted black to provide a nonreflective surface with high emissivity. There are essentially two separate electrical circuits which control and monitor the temperature of the plates. The control circuit includes a thermoelectric module coupled to a water-cooled heat sink and a closed-loop serro with a thermistor embedded in the plate as a sensor.

The monitor circuit consists of a thermistor physically located within the plate and electrically connected to a series circuit allowing the temperature of the plate to be determined very accurately.

During the operation of the scanner, the approximate temperature of each plate is set at some predetermined temperature by adjusting the control circuit. The actual temperature of each plate is determined from the electrical parameters of the monitor circuit. A brief discussion of the methods used to obtain the temperatures from the monitor circuits follows:

The theoretical relationship between resistance and temperature is

$$R = R_o e^{\beta \left[\frac{1}{T} - \frac{1}{T_o}\right]} \qquad (1)$$

where R = resistance (ohms) at temperature T (degrees Kelvin)

R_o = resistance (ohms) at temperature T_o (degrees Kelvin)

β = material constant

e = Naperian base = 2.718

From equation (1) the following equation may be derived

$$T_x = \frac{\ln (R_2/R_1)}{\frac{\ln R_x/R_1}{T_2} + \frac{\ln (R_2/R_x)}{T_1}} \qquad (2)$$

where R_1 = resistance (ohms) at temperature T_1 (degrees Kelvin), one calibration point

R_2 = resistance (ohms) at temperature T_2 (degrees Kelvin), other calibration point

R_x = measured resistance (ohms) at plate temperature T_x (degrees Kelvin) values

The values R_1, R_2, T_1, and T_2 are furnished by the manufacturer for a given thermistor. Thus the only unknown on the right hand side of the equation (2) is R_x. In practice R_x is placed in series with a reference resistance (R_r) of 10 kΩ, and a reference voltage V_r. The voltage across the thermistor (V_m) is monitored by a digital volt meter. From this circuit it is possible to derive an expression for R_x

$$R_x = \frac{R_r}{\frac{V_r}{V_m} - 1} \qquad (3)$$

where R_x = measured thermistor resistance

R_r = reference resistance of 10 kΩ

V_r = reference voltage of 6.155 V

V_m = monitored voltage

The values of V_m for each thermistor are obtained from the operator's log; R_r and V_r are known; thus, it is possible to compute from equation (3) the thermistor resistance (R_x) of each plate. Substituting this value of R_x into equation (2), along with the calibration constants R_1, R_2, T_1, T_2 associated with the same thermistor, one obtains the temperature of the plate (T_x). This procedure is followed for each plate and the temperatures determined. The computer program PLATTEMP has been written to carry out these calculations.

In summary, by using LARS program PLATTEMP and monitor voltages which are found in the scanner operator's log, the temperature of the reference plates may be obtained.

In order to calibrate the data, it is also necessary to have a measure of the radiation emitted from the two temperature plates. This is obtained by averaging 20 values from each plate and assigning the average value as the radiation from the plate. These averaged values for each scan line are stored in samples of the LARS data storage tapes. Each tape contains 288 samples.

Calibration Procedure

A question fundamental to the calibration of the data from the thermal channels is--how total energy received in the wavelength band passed to the detector varies with black-body temperature. Plank's function predicts black-body radiation as a function of wavelength and temperature. Thus, by integrating Plank's function over a waveband for black-bodies of different temperatures, it was possible to establish the relationship between these quantities. A program in the IBM Scientific Subroutine Package was used to perform this integration over the wavelength interval 8-13.5 μm (one of the thermal channels of the University of Michigan Scanner) and for temperatures varying by 0.1°C over a range of -20°C to 60°C (typical terrestrial temperatures). A graph showing the variation in radiation for a temperature range of 21° to 30°C is shown in Figure 2. The graph indicates a very nearly linear relationship between radiant energy and temperature over this range. From the temperature reference plates it is possible to derive a linear equation relating amount of radiation received at the scanner to temperature.

An illustration of the calibration scheme is shown in Figure 3. In practice, however, the calibration is performed by computer. A general discussion of calibration options for LARS Programs may be found in LARS Information Note 071069 by Terry L. Phillips. A discussion of its application to the specific problem of calibration of the thermal channels follows.

From the temperatures of the reference plates (T_1 and T_2) and the digitized voltage output of the scanner from the plates (D_1 and D_2), respectively, the computer derives a linear equation relating temperature to the digitized value of the scanner output.

A general linear equation relating temperature to scanner output may be written in the following form:

$$T = mD + b \qquad (4)$$

where T = temperature

D = digitized scanner output

m and b are constants

It is possible to write a linear equation for each of the temperature reference plates, and from this pair of equations solve for the two constants m and b.

$$T_1 = mD_1 + b \qquad (5a)$$

$$T_2 = mD_2 + b \qquad (5b)$$

where T_1 and T_2 are the temperatures of Plate 1 and 2 respectively

D_1 and D_2 are the digitized scanner responses of radiation from Plate 1 and 2 respectively

Solving equations (5a) and (5b) simultaneously, one obtains for m and b

$$m = \frac{T_1 - T_2}{D_1 - D_2} \qquad (6a)$$

$$b = \frac{T_2D_1 - T_1D_2}{D_1 - D_2} \qquad (6b)$$

Substituting equations (6a) and (6b) into equation (4)

$$T = \left(\frac{T_1 - T_2}{D_1 - D_2}\right) D + \frac{T_2D_1 - T_1D_2}{D_1 - D_2} \qquad (7)$$

results in an equation relating temperature and digitized scanner output in terms of known constants. This equation (Eq. 7) is the one which is programmed into the LARS data processing system.

Implementation of Calibration Procedure: The calibration procedure is implemented within the LARS system through the use of the CHANNEL card. The general form of a CHANNEL card is

CHANNEL A(I/P, Q/, J/R, S/,. . .), B(K/W, X/, L/Y, Z/, . . .)

Where A and B are calibration codes, the integers I, J, K and L are the channels selected, and P, Q, R, S, W, X, Y, and Z are fixed levels inserted for the channels they follow.

The calibration code used for calibrating the thermal data is code 6, and the fixed levels are the temperatures of the temperature reference plates. The channel of course is the channel which contains data from either the 4.5-5.5 µm or 8-13.5 µm wavebands. For example, where the 8-13.5 µm waveband is recorded on channel 2, and the temperatures of the two reference plates are $T_1 = 25.84^{\circ}C$ and $T_2 = 33.82^{\circ}C$. To calibrate this data into degrees centigrade, the CHANNEL card should have the following form:

CHANNEL 6(2/25.84, 33.82/)

Summary

The thermal data from the University of Michigan Scanner may be calibrated using the LARS data processing system. The steps to accomplish this are: (1) determine temperatures of two plates (T_1 and T_2) by inserting monitor voltages from the scanner operator's log into LARS Program PLATTEMP, (2) insert the temperatures T_1 and T_2 in the CHANNEL card.

Acknowledgements

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References

1. P. G. Hasell, Jr. and L. M. Larsen, Calibration of An Airborne Multispectral Optical Sensor, Technical Report ECOM-00013-137, U. S. Army Electronics Command, Fort Monmoth, New Jersey, September, 1968.

2. Terry L. Phillips, Calibration of Scanner Data for Operational Processing Programs at LARS, LARS Information Note 071069, 1969.

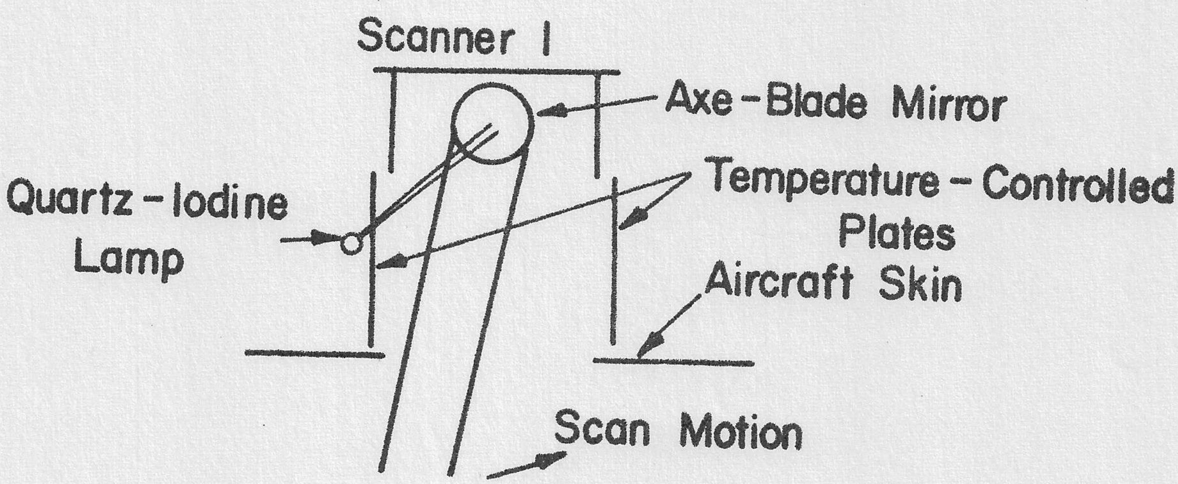

Figure 1. Configuration of reference sources of Scanner 1 (from Technical Report ECOM-00013-137; page 22, figure 17).

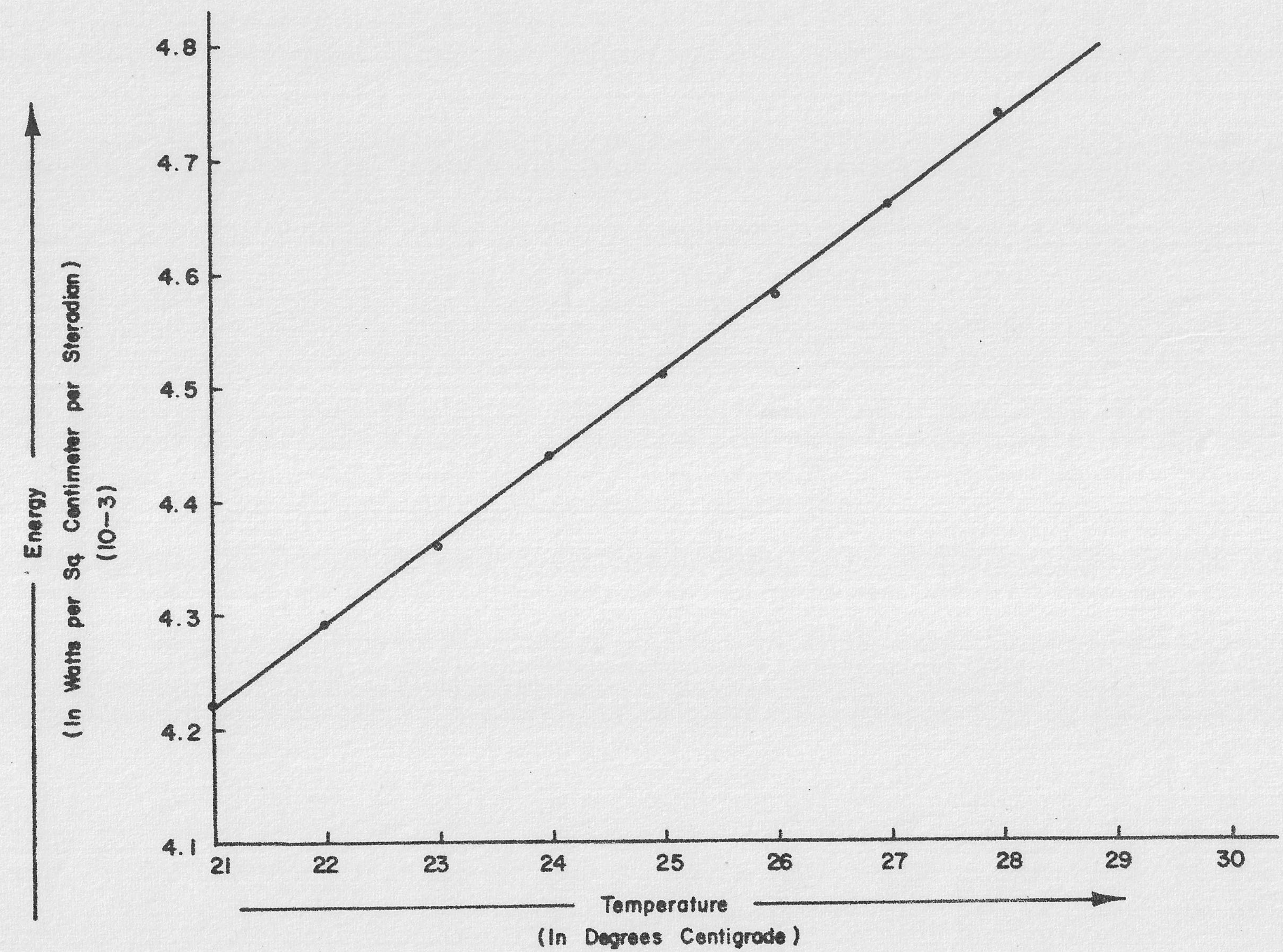

Figure 2. Integral of Plank's Function over 8-13.5 μ versus temperature of the black-body.

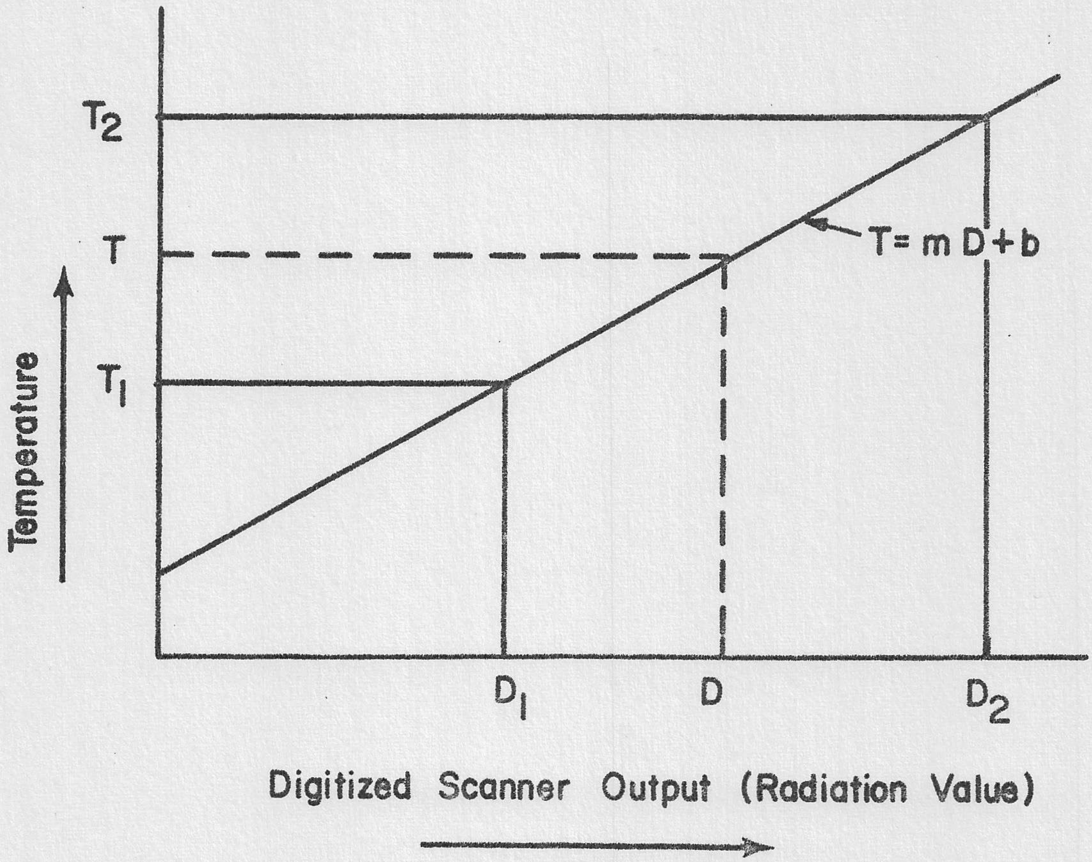

Figure 3. Illustration of calibration method. T_1 and T_2 are temperatures of Plates 1 and 2. D_1 and D_2 are the average radiation value from Plate 1 and 2 respectively. D is the radiation from some target and T is the black-body temperature determined by the calibration method.