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THERMAL RADIOMETER USING LM35 ANALOG SENSORS, CONNECTED TO AN ARDUINO BOARD

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Abstract. The measurement of solar radiation in solar energy research is a key factor not only in obtaining thermal efficiency, but also in the evaluation of the behavior of equipment that uses solar radiation. This radiometer using a pair of LM35 analog temperature sensors, connected to an Arduino board, measures the difference between hot temperatures under a small blackened aluminum disk and the ambient temperature with 95% uncertainty of the instrument.

Keywords: Thermal radiometer, LM35, Arduino

1. INTRODUCTION

Solar radiation, or radiant energy emitted by the sun, is an electromagnetic wave, where about half of the energy is emitted as visible light in the higher frequency of the electromagnetic spectrum and the rest in infrared ultraviolet radiation. The sum of all these energies is called global radiation, i.e., the direct radiation emitted by the sun and the diffuse radiation, dispersed by the atmosphere and measured in W/m^2 (Lester and Myers, 2006). The optical sensors use semiconductor photodiode sensors (Awasthi *et al.*, 2012; Zanesco, 1991; Zanesco and Krezinger, 1992b,a). In the work of Scalon *et al.* (2017), an optical radiometer was constructed using a BPW-34 sensor with a resolution of 1.3 W/m^2.

The authors (Escobedo *et al.*, 1997; Souza and Escobedo, 1995) constructed a thermal radiometer using thermopiles of thin films obtained by evaporation of bismuth and antimony metals, where each set constitutes a thermocouple. Recent work, (Avallone *et al.*, 2016, 2018), the authors describe the construction of a thermal radiometer using two thermocouples "K" connected in series, where the radiometer showed a 20.8 W/m^2 error with a correlation coefficient 0.99. Gomes *et al.* (2011) constructed a radiometer using a LM35DZ measuring the temperature of the cloud projection by a fisheye lens. The data were analyzed by a neural network model and compared with a commercial sensor.

2. BUILDING THE RADIOMETER

The thermal radiometer using two LM35 temperature sensors (LM35, 1999) were constructed based on the mathematical model presented by (Avallone *et al.*, 2018; Scalon and Oliveira, 2015).

The first temperature sensor is in physical contact below a blackened aluminum disk of 20 mm with Sumaterm 95% absorbance ink, as shown in Fig. 1 and measures the hot temperature (T_h). Above the aluminum disk a transparent glass disk of 53 mm diameter and 3 mm thick is installed. There is a 3 mm space between the two disks, reducing the convection generated by heating the aluminum disk.

The second temperature sensor measures the ambient temperature (T_∞). The two sensors for the hot and cold tem-

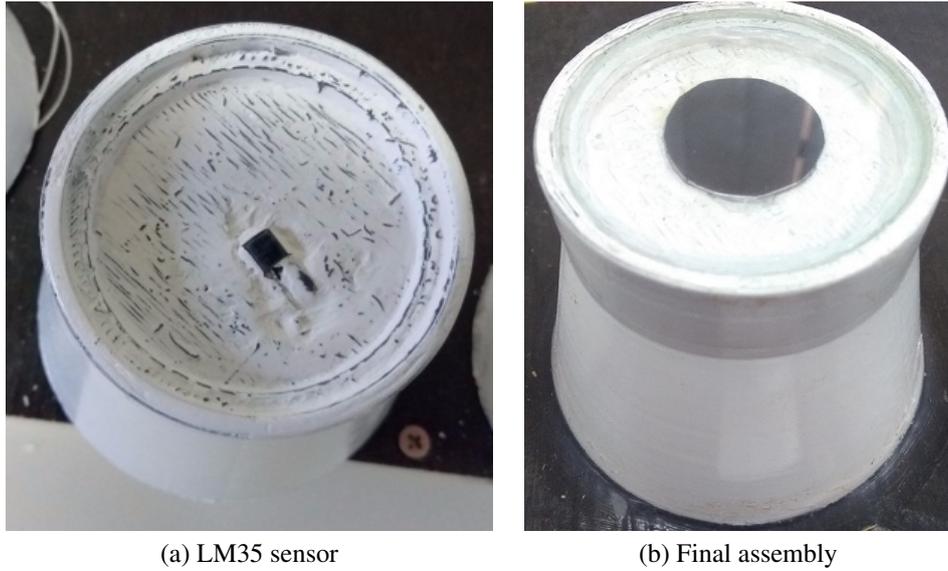(a) LM35 sensor   (b) Final assembly

Figure 1. Aluminum disk and sensor body

perature, are connected to the analog-to-digital converter ADS 1115 (Texas Instruments, 2018). A forced airflow through the ambient temperature sensor ensures the stability of the reference measurements. The difference between the two temperatures ($T_h - T_\infty$) is used for comparison and calibration with the IPMet (Institute of Meteorological Research) pyranometer CMP22 (Kipp & Zonen, 2016) as in Fig. 2.

Figure 2. Radiometer with LM35 in calibration in IPMet

The electronic circuit using the Arduino (Arduino, 2015), the analog-to-digital converter temperature sensors are presented in Fig. 3.

3. RESULTS

The calibration of the radiometer was done using a curve, where the abscissa axis represents the values of the hot and cold temperature difference measured in the sensors in °C and the ordinate axis represents the IPMet sensor, which is the reference in W/m^2, shown in Fig. 4.

Only the points to 15:00 were considered for calibration of the radiometer, due to a shadowing on the reference sensor.
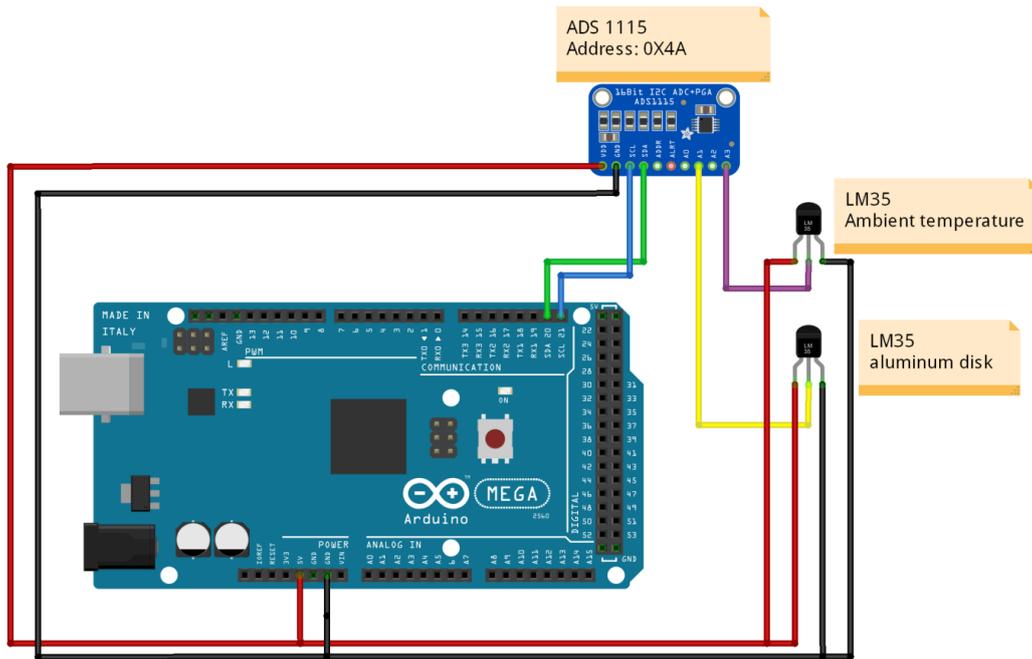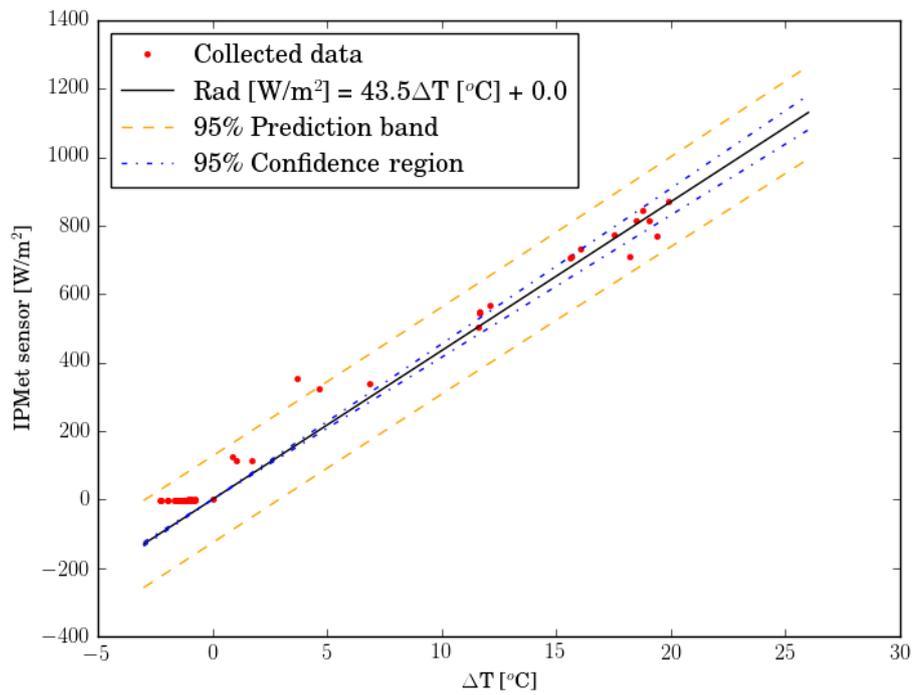
Figure 3. Radiometer electronic circuit

Figure 4. Cloud points for calibration of the radiometer x IPMet

The linear regression applied to the points resulted in Eq. 1.

$$Rad[\text{W/m}^2] = 43.5 \times \Delta T[°\text{C}] + 0.0 \qquad (1)$$

Figure 5 shows the comparison curves between the reference radiometer and the thermal sensor.

4. CONCLUSIONS

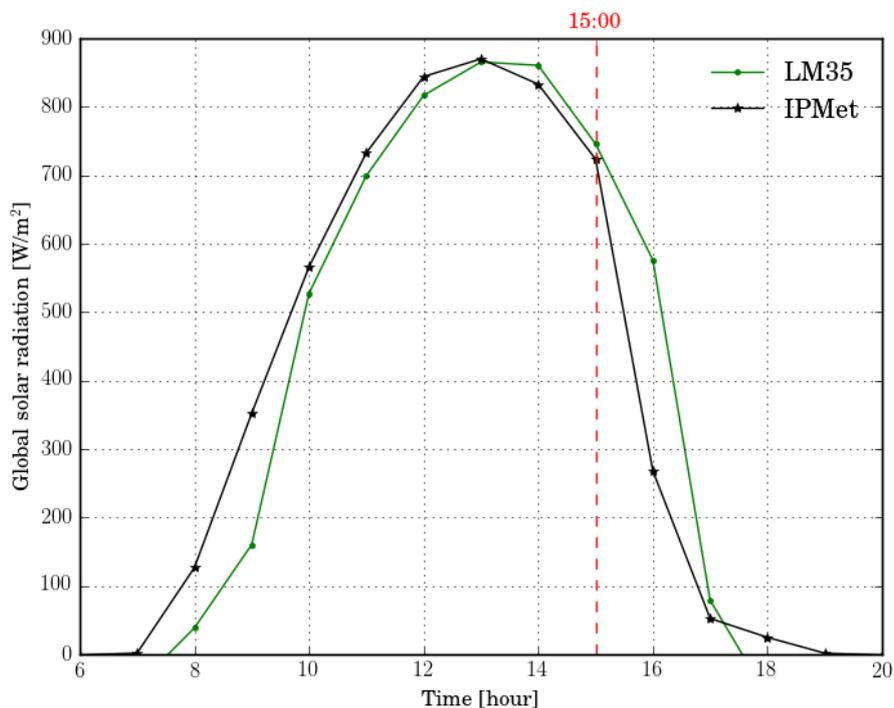The radiometer built with the LM35 thermal sensor presented results consistent with the IPMet reference sensor.

Figure 5. Comparison between the curves of the two radiometers

5. ACKNOWLEDGEMENTS

6. REFERENCES

Arduino, 2015. "Arduino MEGA". URL `https://www.arduino.cc/en/Main/ArduinoBoardMega2560`.

Avallone, E., Mioralli, P.C., Scalon, V.L. and Padilha, A., 2016. "Thermal pyranometer using the arduino platform for data acquisition". In *Contemporary Problems of Thermal Engineering*. Politechnika Slaska - ITC, Katowice - Polônia, Vol. 1 of *044*, pp. 303–311.

Avallone, E., Mioralli, P.C., Scalon, V.L., Padilha, A. and Oliveira, S.d.R., 2018. "Thermal Pyranometer Using the Open Hardware Arduino Platform". *International Journal of Thermodynamics*, Vol. 21, No. 1, pp. 1–5. ISSN 1301-9724. doi:10.5541/ijot.5000209000. URL `http://dergipark.gov.tr/doi/10.5541/ijot.5000209000`.

Awasthi, S., Dubey, A., Kellar, J.M. and Mor, O., 2012. "Design and simulation of eletronic instruments for solar energy measurement system". *International Journal of Scientific & Engineering Research*, Vol. 3, No. 1. ISSN 2229-5518.

Escobedo, J.F., Frisina, V.A., Chaves, M.A. and Oliveira, A.P., 1997. "Radiômetros solares com termopilhas de filmes finos - II Desempenho". *Revista Brasileira de Aplicações de Vácuo*, Vol. 16, No. 1.

Gomes, J.M., Ferreira, P.M. and Ruano, A.E., 2011. "Implementation of an intelligent sensor for measurement and prediction of solar radiation and atmospheric temperature". In *Sensors Journal, IEEE*. Floriana - Malta, pp. 1–6. ISBN 978-1-4577-1403-0. doi:10.1109/WISP.2011.6051713.

Kipp & Zonen, 2016. "CMP22, the best secondary standard pyranometer available - Kipp & Zonen". URL `http://www.kippzonen.com`.

Lester, A. and Myers, D., 2006. "A method for improving global pyranometer measurements by modeling responsivity functions". *Solar Energy*, Vol. 80, No. 3, pp. 322–331. ISSN 0038092X. doi:10.1016/j.solener.2005.02.010. URL `http://linkinghub.elsevier.com/retrieve/pii/S0038092X05000885`.

LM35, 1999. "LM35 Precision Centigrade Temperature Sensors". URL `http://www.ti.com/lit/ds/symlink/lm35.pdf`.

Scalon, V.L., Avallone, E., Pansanato, C. and Ito, M., 2017. "Development of a low cost pyranometer for solar radiation measurements". ABCM. doi:10.26678/ABCM.COBEM2017.COB17-0524. URL `http://abcm.org.br/anais-de-eventos/COB17/0524`.

Scalon, V.L. and Oliveira, S.D.R., 2015. "Análise teórica de um piranômetro plano". Universidade Estadual Paulista

"Júlio de Mesquita Filho", p. 4.

Souza, J.L. and Escobedo, J.F., 1995. "Construção de um saldo radiômetro com termopilha de filme fino e avaliação de sua performance". *Revista Brasileira de Meteorologia*, Vol. 10, No. 1/2, pp. 29–36.

Texas Instruments, 2018. "ADS 1115 Digital converter". URL `http://www.ti.com/lit/ds/symlink/ads1115.pdf`.

Zanesco, I. and Krezinger, A., 1992a. "A Cheap PV Pyranometer for developing countries". In *11th Photovoltaic energy conference, Montreux Swizerland*. Montreux - Suíça.

Zanesco, I., 1991. *Analise e Construçao de um Piranômetro Fotovoltaico*. Dissertação de Mestrado, Universidade Federal do Rio Grande do Sul, Porto Alegre.

Zanesco, I. and Krezinger, A., 1992b. "On the threshold of the accuracy of using silicon solar cells to measure global solar irradiance". In *11th Photovoltaic energy conference, Montreux Swizerland*. Montreux - Suíça.

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