Journal of Physics: Conference Series

All sky scanning cloud monitor for NLOT site survey

All sky scanning cloud monitor for NLOT site survey

T K Sharma[⋆,†], Padmakar Parihar[⋆] and P M M Kemkar[⋆]

[⋆]Indian Institute of Astrophysics, Block II, Koramangala, Bangalore, Karnataka, India-560034

E-mail: [†]tarun@iiap.res.in

Abstract. Monitoring local sky for the cloud is one of important task before setting-up a new observatory. Here we present the design, implementation and initial results of a scanning type cloud monitor developed in Indian Institute of Astrophysics, Bangalore, India. The new cloud monitor is expected to be used in search for a potential site for India's National Large Optical Telescope project. The instrument works on the principle of detection of the Infrared radiations from the clouds. A number of thermopile sensors are arranged in the form of a circular array and are rotated in azimuth to cover the whole sky. An analog circuit was designed and fabricated to amplify the weak output of the thermopile. A customized data acquisition devise is developed for recording the output of the sensors on SD card. LabVIEW based data analysis software is developed to process raw data as well as to generate the cloud map of the sky.

1. Introduction

Availability of large number of clear nights is one of the prime requirement for any observatory and before setting-up a new observatory, this parameter needs to be reliably determined. For any existing observatory, monitoring of clouds on real time also helps to effectively use their automated telescopes. Furthermore, in case of manual operation of a telescope, observer can select from equally desirable targets based on local sky transparency. All these objectives can be met if observatory operate a very reliable automated all sky cloud monitor which regularly broadcasts local sky condition.

The traditional method for monitoring sky-condition by means of visual observation is extremely tedious and very subjective. Whereas, using a CCD camera attached with a fish-eye lens to capture whole sky in optical wavelengths is a great improvement over manual observation method. Several such devices usually called All-Sky Night Camera have been used by different groups [1, 2, 3]. A CCD camera based all sky monitor is an inexpensive tool, however, appearance of clouds in the optical images is very deceptive due to its strong dependency on apparent optical sky brightness which in turn depend on phases of the Moon, local light pollution and other atmospheric variables. Automated tools developed to derive a quantitative information of cloudiness from all sky images, usually fails to reliably extract cloud information and results are often found to be inconsistent with other methods[4].

One of the best methods of observing clouds from the ground is to make use of infrared radiation coming from cloud either due to thermal radiation of cloud itself or cloud can act like screen which reflects radiation originating from relatively warmer Earth surface. In the $8-14\mu$ mid-IR atmospheric window, clear sky appears cold and clouds appear warm. The effects of variable sky brightness becomes minimal and hence a mid-IR sensor provides the greatest cloud/sky discrimination. A mid-IR imaging camera can be best suited for this purpose, however it is too expensive and only few such camera have been used for the cloud monitoring [5, 6]. In attempts to provide an inexpensive cloud detector working in mid-IR range, Ashley & Jurcevic (1991) developed a cloud detector based on pyroelectric infrared element which requires mechanical chopping[7]. Subsequently Clay et.al. (1998), used infrared thermopile device for cloud detection[8]. Thermopile is very inexpensive infrared sensor, most suitable for cloud monitoring without cooling the systems and requires simple detector electronics. Both cloud monitors mentioned above uses single detector with limited field of view and can only detect cloud present in certain direction.

In Indian Institute of Astrophysics we have initiated a program to develop site survey instruments. The instruments are developed as a part of the site survey program for the NLOT (National Large Optical Telescope) project, which will be an 8−10 meter class state of the art telescope. The telescope will be installed at some suitable site in the country. All Sky Scanning Cloud Monitor is one of the instrument what we have developed for the purpose of surveying potential sites. The device has got high sensitivity, provides radiometric output, cover whole sky, works in fully automated mode and also very cost effective.

2. Operating principle

Measurements of the sky infrared radiation above 5 μm are sensitive to the presence of the clouds in particular between 8 to 14 μm[9]. Presence of clouds produces an enhanced signal compared to the clear sky. The signal also has an effect of atmospheric humidity, and gets enhanced at lower elevations because sensor has to look through increased air−mass or more water vapor. The device works on the principle of measurement of sky temperature for detection of clouds.

Thermopile is device which is composed of a large number of thermocouples connected in series. The device works on the principle of Seebeck effect and converts the thermal energy to electrical energy, when its two junctions are subjected to a temperature difference. The two junctions are called measuring and the reference junctions. A thermopile sensor generates a voltage proportional to the temperature difference between the two junctions, which means thermopile can be used only for differential temperature measurement. Absolute temperature measurement requires output of the thermopile sensor be corrected for changes in the reference junction temperature. This correction is called the ambient temperature correction.

TPS334L5.5 thermopile sensor from Perkin Elmer is used for measuring sky temperature. Sensor comes with an inbuilt IR lens which gives it a field of view of 7° and has a flat pass-band from 2 to 22 μm. The sensor has a sensitive area of $0.7\times0.7\ mm^2$, and high sensitivity of 55 V/W, and a small noise voltage of 35 $nv/\sqrt{Hz}$.

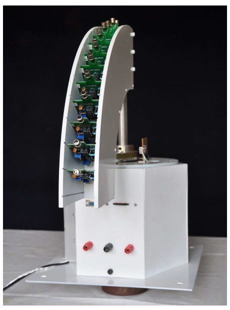


Figure 1. Laboratory picture of the cloud monitor instrument.

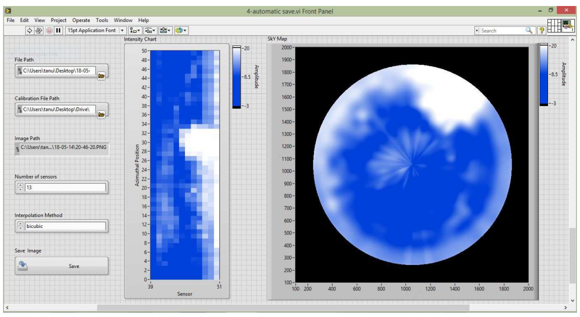


Figure 2. A screen captured image of the front panel of software developed using LabVIEW.

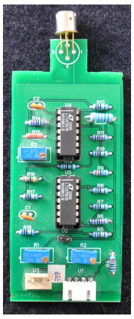


Figure 3. Sensor interface board.

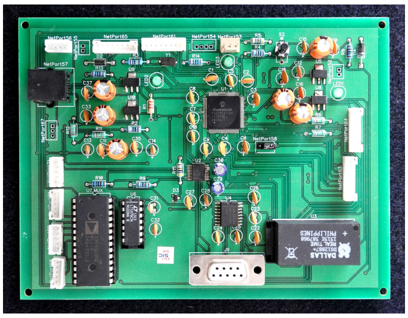


Figure 4. Data acquisition and logging board.

3. Instrument structure

Instrument structure is shown in figure 1 . Each Thermopile sensor has a field of view of 7°, which means single sensor can cover only a small part of the sky. 12 sensor units are mounted on the circular arc, which covers 84 ° of the sky. This scanning unit is rotated around azimuth in steps of 7° to cover the whole sky. The scanning unit is rotated by a stepper motor and timer belt−pulley based drive. All the electronics like data acquisition and logging board, SD card module, stepper motor driver and optical isolation boards are mounted inside the hexagonal box structure of the instrument. A Hall effect based home and limit switch is also provided to determine the initial position of the scanning unit.

4. Instrument electronics

Different electronic modules of the instrument like sensor interface board, data acquisition and logging board, optical isolation board, stepper motor driver and limit switch interface ware designed and fabricated locally. Two important boards are described in this section.

4.1. Sensor interface board

Thermopile generate a voltage output which is proportional to the temperature difference between the two junctions of the sensor. This makes it necessary to either operate the sensor at a constant ambient temperature or to compensate the sensor output for changes in ambient temperature. Figure 3 shows the sensor interface board. We have modified the circuit used by Clay et.al. (1998) for their single channel cloud monitor[8]. To minimize noise as well as EMI, sensor is mounted on the board itself. The board amplifies the weak output of the thermopile, it can also compensate the thermopile output for changes in ambient temperature.

4.2. Instrument control and Data acquisition board

A customized network based data acquisition and logging board is developed for the instrument[10]. Figure 4 shows the board with all the components mounted. The board also control all the functionalities of the instrument like initialization, homing, movement of scanning unit, data acquisition and logging. A high end micro-controller PIC18F97J60 from Microchip is used as the main processor. An external ADC MAX1144 converts analog output of the sensor to digital and this data is stored on an SD card. On board RTC unit provides the time information which is required for time-stamping the data. Data can also be transmitted to remote server using either serial or Ethernet connectivity.

5. Sensor calibration and ambient temperature compensation

Multiple sensors are used in the instrument to cover the whole sky. No two sensors give same response when subjected to the same excitation source. Also the sensor interface boards used

Journal of Physics: Conference Series **595** (2015) 012032 doi:10.1088/1742-6596/595/1/012032

to amplify the weak output of the sensors do not provide same gain characteristic. The main reason being the different offset voltages in each op−amp and the tolerances of the gain providing components. This makes it necessary to calibrate each sensor board.

The output voltage of the thermopile is a function of the object temperature and the ambient temperature i.e. the temperature of the reference junction. This relation can be expressed as

$$V = K.F(T_{obj}, T_{amb}) \tag{1}$$

Where V is output voltage of thermopile, K is a constant, T_{obj} and T_{amb} are object and ambient temperature respectively.

Equation can be expanded to include the calibration temperature T_{ref}, which can be any arbitrary temperature at which sensors are calibrated. Expanded equation can be written as

$$V = K.F(T_{obj}, T_{ref}) - K.F(T_{amb}, T_{ref}) \tag{2}$$

The function $F(T_1, T_2)$ is obtained by observing the output of the thermopile sensor which is kept at constant ambient temperature and is looking at an object whose temperature is changed in steps. Equation 2 establishes the relation between the output voltage of thermopile sensor, object temperature and the ambient temperature. For a fixed ambient temperature we can use an equation or a lookup table to deduce the object temperature from the output voltage of thermopile sensor. But if the ambient temperature itself varies, the output voltage will vary for the fixed object temperature. This means we have to correct the output of the thermopile sensor for changes in the ambient temperature. We have implemented the software based or digital ambient temperature compensation scheme. In this scheme uncompensated output of thermopile and the thermistor output are read, and all calculations are performed by the software to measure the actual object temperature. The actual procedure of this compensation scheme is discussed in section 5.3.

5.1. Thermistor calibration

Thermopile sensors are equipped with an inbuilt thermistor, which can be used for ambient temperature compensation. This thermistor is in contact with the reference junction and measures the ambient temperature. Two parameters $\beta - value$ and the resistance R_0 at temperature T_0 are used to characterize the thermistor. Thermistor used in our sensor has a $\beta - value$ of 3964 and value of resistance at 25 °C is 30 KΩ. Resistance of the thermistor at any other temperature can be expressed as

$$R = R_0.e^{\beta(1/T - 1/T_0)} \tag{3}$$

The thermistor is placed in series with another resistor of fixed value of 30 KΩ, and this combination is biased with a voltage of 1 V. The bias voltage is kept at minimum to avoid the self-heating effect in thermistor. Voltage output is taken at the other resistor and is fed to the op-amp with gain of 2. This voltage output is read by the data acquisition board, and is converted back to the equivalent ambient temperature by the high level software.

5.2. Thermopile calibration

Thermopile sensor is calibrated by exposing the thermopile to an object whose temperature can be changed, while ambient temperature remains constant. The output voltage is measured for different object temperatures. For small temperature range the thermopile response is linear with constant sensitivity. But this is not the case for wide range, also results obtained using constant sensitivity are less accurate.

We have designed a setup for calibrating the sensors. The setup consists of a Peltier element, which acts as an object whose temperature can be varied as desired. This Peltier cooler is mounted on a heat sink. Sensor module is placed near to the Peltier element in such a way so that the whole sensor field of view is covered by the Peltier element, and no radiation falls on the sensor from the nearby objects. One thermistor is placed in close contact with the front surface of the Peltier element to measure its temperature. Heat sink compound was used to keep this thermistor in its place to have better thermal coupling between the thermistor and the Peltier element, so that the thermistor measures the correct object temperature. Using this setup, we were able to calibrate all the sensors from -8 degree to 50 degree centigrade. the response of the sensor is found to be quadratic in nature and can be expressed as

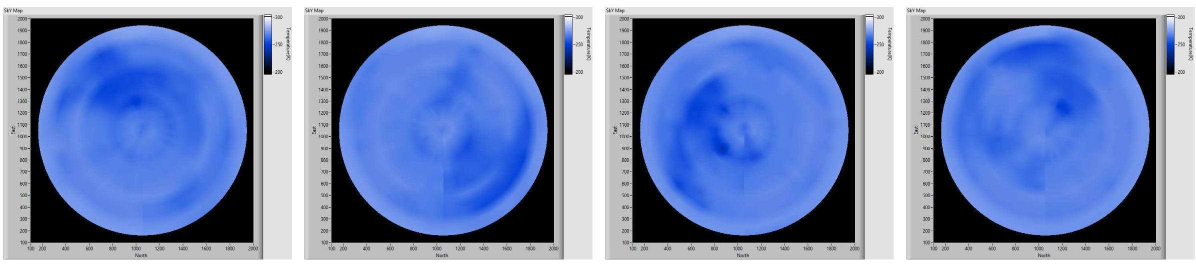
$$V = I + B_1 T + B_2 T^2 \tag{4}$$

Calibration procedure gives separate values of I, B_1, B_2 and calibration temperature for each sensor. All these values are supplied to the software in a calibration file.

5.3. Ambient Temperature Compensation

Followings are the steps, which are followed in software based ambient temperature compensation

(i) Sensor is calibrated at fixed ambient temperature.
(ii) A relation is obtained between the output voltage of thermopile and the object temperature.
(iii) The uncompensated thermopile output voltage is measured.
(iv) Thermistor output is measured and converted to the ambient temperature.
(v) The calibration temperature is put in the equation 4.
(vi) Present ambient temperature is put in the equation 4.
(vii) A difference is taken and this is added to the uncompensated thermopile output voltage.
(viii) Now the object temperature is calculated back by putting the compensated voltage in the equation 4 and solving for the temperature.



(a) 19-39-24 (b) 19-49-57 (c) 20-13-6 (d) 20-36-17

Figure 5. Sky maps generated by the instrument.

6. Instrument Software

Two different software's are developed for the instrument. These are:− instrument control and data logging software, and the data analysis software. Instrument control and data logging software is the low level software, which directly controls the hardware. The software sits inside the data acquisition and logging board and is developed using embedded C language from Microchip. The software perform tasks like controlling stepper motor for operating scanning unit, operation of analog multiplexer, analog to digital conversion of sensor outputs, storage of data onto SD card and finally providing serial and Ethernet connectivity to the instrument. A LabVIEW based data analysis software is developed. Figure 2 shows the snapshot of the software with sky map. This software reads the raw data from a file called Data File generated by the instrument, and converts it to the corresponding sky map. The software performs different operation like converting the ADC numbers to the corresponding voltages, compensating these voltages for ambient temperature variations, calculating the sky temperature from the compensated voltage, and finally generating the sky map. Other than data file, one more file called Calibration File is also used by the software. This file keeps all the calibration coefficients and the calibration temperature for each sensor.

7. Results and discussion

Before proceeding with the full scanning system, individual sensors are tested for sensitivity to the clouds. A setup was made consisting of two sensor modules and a webcam looking in the same direction. Data was acquired continuously using NI USB-6008 data acquisition module, and images were stored. Data was collected over the period of one month. A direct relationship was found between the voltage level of the sensor output and the percentage cloud cover in the sensor field of view. Also the outputs of the two sensors showed almost similar signal pattern, suggesting similar behavior for same kind of excitation. Hardware based ambient temperature compensation was used for this test.

Careful calibration procedure combined with the software based ambient temperature compensation scheme provides the temperature measurement accuracy of $\pm 1^\circ$. This kind of measurement accuracy is quite good considering the sky temperature for the clear sky (-60° to -40°) and the clouds (-20° to 10°) at IAO Hanle, Ladakh. Before installation at Hanle, instrument was tested in IIA Bangalore. As evident in figure 2, The temperature of the cloudy and clear sky are found to be about 20° and -5°. The cloud temperature was found to depend on the thickness of the cloud, thicker the cloud higher the temperature is measured. The reason for the higher observed sky temperature at Bangalore is primarily due to increased airmass and higher water vapor content in the local atmosphere. Figure 5 shows few sky maps generated by instrument at Hanle along with time and temperature scale. The bottom and left side of each frame indicates the north and east directions.

While operating the device at IAO Hanle, we found that at higher wind-speed, scanning unit of device start shaking and also gets rotated, which smears out the sky map. The primary reason being the use of simple Timer belt−pulley based drive. We are working on improving the instrument structure and drive mechanism, while keeping the electronics same. The new design will also protect the instrument in case of rain and snowfall. Data analysis software will be improved to provide the percentage cloud cover. Before we start regular use of the device, a thorough comparison will be made between the results generated by the IR scanning cloud monitor and CCD based all sky cloud monitor.

References

[1] Pereira W E 2003 PhDT
[2] Pickering T E 2006 *SPIE* **6267** 62671*A*
[3] Skidmore W, Riddle R, Schöck M, Travouillon T, Els S, Walker D and Magnier E 2011 *RMxAC* **41** 70 − 3
[4] Shamir L and Nemiroff R J 2005 *PASP* **117** 972 − 977
[5] Suganuma M, Kobayashi Y, Okada N, Minezaki T, Aoki T, Enya K, Tomita H and Koshida S 2007 *PASP* **119** 567 − 82
[6] Sebag J, Andrew J, Klebe D and Blatherwick R D 2010 *SPIE* **7733** 773348
[7] Ashley M C B and Jurcevic J S 1991*Publ. Astron. Soc. Aust.* **9** 334 − 35
[8] Clay R W, Wild N R, Bird D J, Dawson B R, Johnston M, Patrick R and Swell A 1998 *Publ. Astron. Soc. Aust.* **15** 332 − 5
[9] Sloan R, Shaw J H and Williams D 1955 *J. Opt. Soc. Am.* **45** 455
[10] Sharma T K and Parihar P S 2014 *International Journal of Engineering* **8** 22 − 29