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MICROTHERMAL INSTRUMENT FOR MEASURING SURFACE LAYER SEEING

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ABSTRACT

Microthermal fluctuations are introduced by atmospheric turbulence very near the ground. In order to detect microthermal fluctuations at Fuxian Solar Observatory (FSO), a microthermal instrument has been developed. The microthermal instrument consists of a microthermal sensor, which is based on a Wheatstone bridge circuit and uses fine tungsten filaments as resistance temperature detectors, an associated signal processing unit, and a data collection, & communication subsystem. In this paper, after a brief introduction to surface layer seeing, we discuss the instrumentation behind the microthermal detector we have developed and then present the results obtained. The results of the evaluation indicate that the effect of the turbulent surface boundary layer to astronomical seeing would become sufficiently small when installing a telescope at a height of 16m or higher from the ground at FSO.

Key words : Microthermal measurement — site testing — instrumentation

1. INTRODUCTION

Atmospheric turbulence results in refractive index inhomogeneities in the air, and disturbs light beams passing through the turbulent air. The magnitude of such microthermal fluctuations within surface layers is usually maximum near the ground. In consequence, surface layer turbulence degrades optical image quality. Microthermal instruments have been designed and developed to measure the optical seeing in the surface layer. New Vacuum Solar Telescope (NVST) is proposed to be installed at the Fuxian Solar Observatory (FSO) of the Yunnan observatory. For the measurement of seeing in the surface layer, a microthermal device for detecting surface layer temperature fluctuations and for estimating their contribution to the seeing has been developed and recently installed at FSO. By measuring the surface layer seeing using such a microthermal instrument, it is possible to evaluate solar image degradation due to atmospheric turbulence within a height of a few meters above the ground. This information can be used to determine the height of the telescope location in order to achieve better seeing conditions.

The next section presents a brief overview of the principles governing microthermal turbulence and its relationship to astronomical seeing. In Section 3, we describe the microthermal instrument. In Section 4, results and discussions are presented followed by conclusions in Section 5.

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2. PRINCIPLE OF SEEING MEASUREMENT

Atmospheric seeing is caused by variations in the refractive index of the atmosphere. These refractive index changes are characterized by temperature fluctuations in the air. By measuring the temperature fluctuations, it is possible to derive the refractive index structure constant, and thus the contribution to atmospheric seeing. Fried's parameter r_0 represents the telescope aperture diameter, for which the diffraction limited image resolution is equal to the full width at half maximum (fwhm) of the seeing limited image. The relationship between this parameter and atmospheric turbulence has been obtained by Fried (1966) as

$$r_0 = (16.7\lambda^{-2} \int_0^\infty C_N^2(h)dh)^{-3/5}, \qquad (1)$$

where h is the height through the atmosphere, C_N^2 is the refractive index structure constant and λ is the wavelength. From the theory of wave propagation in turbulent media given by Tatarski (1961) and its relevant application to astronomical seeing quality (Roddier 1981), the relationship between seeing (ε_{fwhm}) and r_0 is given by Dierickx (1992) as

$$\varepsilon_{fwhm} = 0.98\frac{\lambda}{r_0}, \qquad (2)$$

and hence

$$\varepsilon_{fwhm} = 5.25\lambda^{-1/5}(\int_0^\infty C_N^2(h)dh)^{3/5}. \qquad (3)$$

The refractive index structure constant in this case can be taken to represent the sum of the contributions from all turbulent layers in the atmosphere. In order to assess the data from an astronomical site, it is not sufficient to measure optical turbulence from the whole atmosphere, but also to evaluate the relative contribution due to the surface layer. This information is valuable for deciding the height for locating the telescope above the ground in order to obtain better angular resolution. The turbulence contributions to seeing (ε_{total}) originating from different layers do not add linearly since from Eq. (3):

$$\varepsilon_{total} = (\sum_i \varepsilon_i^{5/3})^{3/5}, \quad (4)$$

where ε_i is the seeing contributed by i^{th} turbulent layer, obtained by replacing the integration range in Eq. (3). The relationship between refractive index structure constant (C_N^2) and the temperature structure constant (C_T^2) at height h is given by

$$C_N^2(h) = (\frac{80 \times 10^{-6} \times P(h)}{T^2(h)})^2 C_T^2, \quad (5)$$

where, $P(h)$ and $T(h)$ are the pressure in millibar (mb) and the absolute temperature in Kelvin (K) respectively at the height h in meter. As defined by Obukhov (1949), the temperature structure constant, for a Kolmogorov type spectrum, is related to the temperature structure function as

$$D_T(x, h) = C_T^2(h) x^{2/3}. \quad (6)$$

Following Barletti (1974) and Marks et al. (1996), the temperature structure function is in turn computed as

$$D_T(x, h) = \langle [T(S_1) - T(S_2)]^2 \rangle, \quad (7)$$

where, $T(S)$ is the temperature at point S, x represents the horizontal distance between two sensors at the same height, and angle bracket indicates an average over time. The method used to determine C_T^2 involves measurement of the temperature function $D_T(x, h)$, between two points at same level. By measuring the temperature differences at two points which are horizontally separated, we can infer the value of C_T^2, as long as the separation distance lies between the inner scale and the outer scale of the turbulent motion.

3. DESCRIPTION OF THE INSTRUMENT

The microthermal instrument which we developed can be divided into three parts. Fig. 1 shows the schematic of the whole system and the complete circuit diagram is shown in Fig. 2. In describing the microthermal instrument we will consider the microthermal sensor in Section 3.1, the signal processing unit in Section 3.2, the data collection & the communications subsystem in Section 3.3.

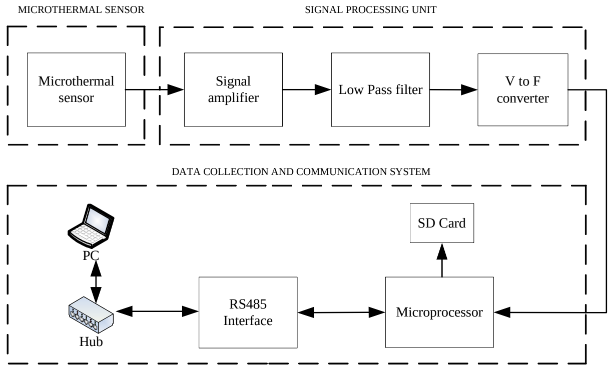

Fig. 1.— A schematic of the microthermal system

3.1 Microthermal Sensor

The measurements of C_T^2 was taken using pairs of microthermal sensors, the resistance of which varied in proportion to the temperature micro-fluctuations associated with the optical turbulence. This microthermal instrument is based on a Wheatstone bridge circuit and uses fine tungsten filaments as resistance temperature detectors. The length of a tungsten fiament is chosen that its effective resistance comes out to be $\sim$ 200Ω at room temperature. This yields a temperature resolution of $\sim$ 0.01°C for the system. For recording the instantaneous ambient temperature around the microthermal sensors with an accuracy of 0.1°C, AD590 RTD temperature sensor and AD acquisition card based on PCI bus for analog signal input from AD590 are used. Three pairs of microthermal sensors are mounted at the height of 8, 12 and 16meter above the ground on the mast, each pair being separated horizontally by approximately 1meter.

3.2 Signal Processing Unit

The microthermal sensor whose resistance changes according to microthermal fluctuations, produces a variable voltage at the instrumentation amplifier. The amplifier output is sent to V/F converter via a low pass filter, which provides the output pulse train at a frequency precisely proportional to the applied input voltage. We use the low noise INA122 amplifier, and the resister R2 in Fig. 2 was sized to 2.2K in order to obtain an amplification factor of 100. In order to convert the analog signal from the amplifier into digital format, we use LM331 V/F converter which has wide range of full scale frequency. For long distance data transmission from signal processing unit to data collection and communication subsystem, and high precision application, a general A/D converter has many shortcomings, thus we use LM331 V/F converter instead of general A/D converter. The position of the mast is shown in Fig. 3.

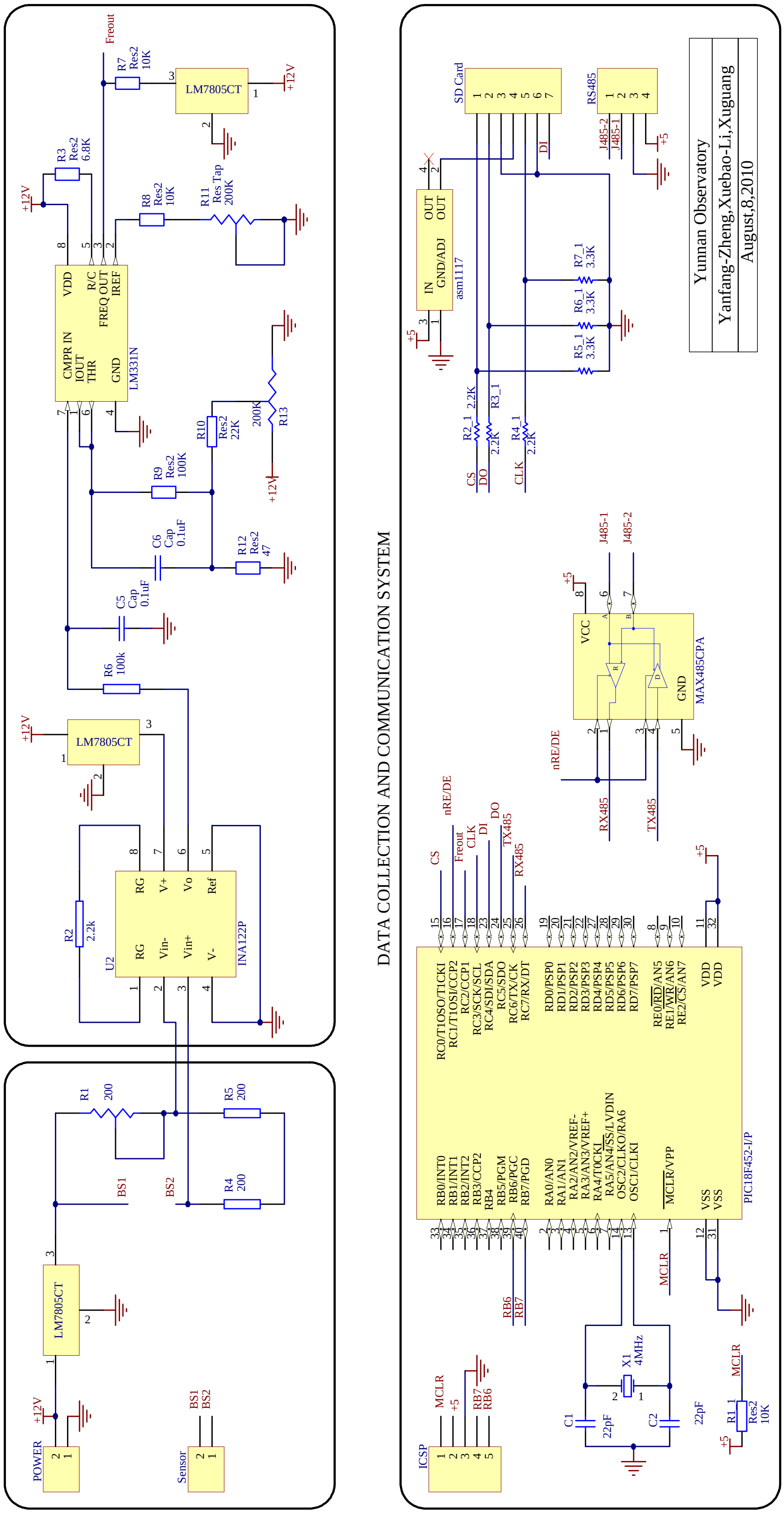

Fig. 2.— Microthermal instrument circuit including signal processing unit, data collecting and communication system

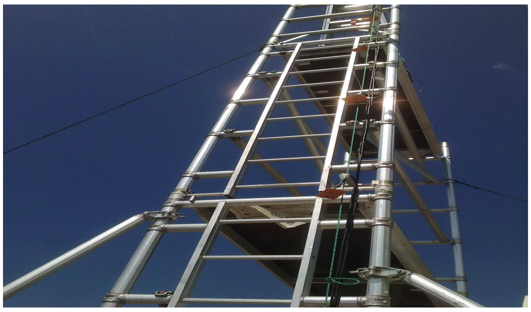

Fig. 3.— The instrumented mast during the April-May 2010 campaign

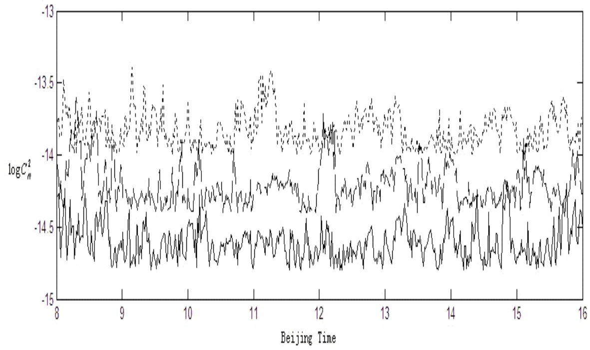

Fig. 4.— Temporal evolution of C_N^2 on 08 April, 2010. Solid lines represent the 16m level, long dashes represent the 12m level, and dots represent the 8m level.

3.3 Data Collection and Communication Subsystem

The pulse signal from the signal processing unit is transported to the data collection unit. We use PIC18F452 microchip as microprocessor of the data collection subsystem integrating Capture/Compare/ PWM (CCP) modules which can capture the pulse train event. With the help of the microprocessor, data is immediately processed and transmitted to a secure digital (SD) card, which is connected to the microprocessor via Serial Peripheral Interface (SPI) protocol. Each microthermal instrument must be connected to the hub, which has multiple channels. The commands from the computer are transmitted to each microthermal instrument via the hub using RS485 protocol, in order to make multiple microthermal devices capable of collecting the data simultaneously. Atmospheric pressure is almost the same within a height of 16m at FSO. Its observed value was ∼830mb which has been used in our further data analysis.

4. RESULTS AND DISCUSSIONS

The various microthermal sensors need to be calibrated since their electrical components are not identical and further, the data collected in the SD card has units of frequency and not temperature. After the microthermal measurement, the data collected in the SD card was processed using a PC. Microthermal data were successfully recorded on April and May, 2010 at FSO. Due to bad weather, only few days of data were available. The results of measurement were familiar in these days, and the data on April 8, 2010 was relatively complete, thus only the data of this day are presented. The values of C_T^2 were measured every second and averaged over one minute. These data were used to determine the values of C_N^2. Temporal evolution of C_N^2 on 08 April, 2010 during 8:00-16:00 Beijing time at each of the three levels has been illustrated in Fig. 4. It decreases sharply but nonlinearly with altitude.

We can evaluate the seeing contribution due to a slab of turbulent layer using Eq. (3) by assuming a power law variation for C_N^2 within a slab. The heights of the slabs range from 4 to 8m, 8 to 12m, and 12 to 16m. Thus we can calculate the values of seeing ε_i in the different layers above the ground. It decreases rapidly from 4 to 16meter height. According to the plots in Fig. 5, the average seeing ε_i for the lower (4 - 8m), middle (8 - 12m) and upper (12 - 16m) slabs are $1.21''$, $0.78''$ and $0.58''$ respectively.

Echevarria et al. (1998) have mentioned that the local value of the seeing is considered to be zero arcsecond at a height of ∼100m from the ground, and it increases as light passes through turbulent boundary layers of the atmosphere below 100m. They have also concluded that the total value of the seeing ε_{total} is given by the relation

$$\varepsilon_{total} = (\varepsilon_{SL}^{5/3} + \varepsilon_{FA}^{5/3})^{3/5}, \qquad (8)$$

where, ε_{SL} is the local value of the seeing measured for a particular slab and ε_{FA} is the seeing that one would observe at a height of 100m. We have taken the value of $\varepsilon_{FA} = 0.52''$ given by Echevarria (1998) and P. Pant et al. (1999). From the above, we learn that the value of surface layer seeing decreases sharply with altitude. Considering the seeing contribution due to the 12 to 16m slab as $0.58''$, and adopting the value of ε_{FA} in Eq. (8), we estimated the total value of the seeing ε_{total} as $0.83''$. Since the seeing contribution due to 16 to 100m slab can be neglected, if the telescope is located above 16m from the ground, a better total value for seeing of $\sim 0.5''$ can be obtained, and it can reduce the influence of temperature fluctuations.

5. CONCLUSIONS

We have designed and constructed several microthermal instruments for measuring the surface layer seeing.

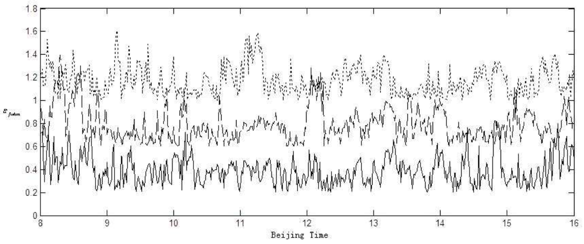

Fig. 5.— Seeing measurements obtained using microthermal instrument. Solid lines represent the 12 - 16m, long dashes represent the 8 - 12m, and dots represent the 4 - 8m.

We have operated the system at the Fuxian Solar Observatory in Yun Nan province, China, and shown the initial results. Microthermal fluctuations due to surface layer turbulence decrease sharply with altitude. The effect of the turbulent surface boundary layer to astronomical seeing would become sufficiently small and we can obtain a better total value for seeing of $\sim 0.5''$, when installing a telescope at a height of 16 m or higher from the ground. Our future plans include continuous microthermal measurements at FSO, the integrated measurements using microthermal instrument with a Solar Differential Image Motion Monitor (S-DIMM), and deployment of microthermal instrument in other sites.

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