University of Tokyo DIMM
– A Portable DIMM for Site Testing at Atacama–

Kentaro Motohara[a], Mamoru Doi[a], Takao Soyano[b], Masuo Tanaka[a], Kotaro Kohno[a], Takashi Miyata[a], Naruhisa Takato[c], and Fumihiro Uraguchi[c]

[a]Institute of Astronomy, University of Tokyo, Osawa, Mitaka, Tokyo 181-0015, Japan
[b]Kiso Observatory, University of Tokyo, Mitake, Kiso, Nagano 397-0101, Japan
[c]Subaru Telescope, North A'ohoku Place, Hilo, HI 96720, USA

ABSTRACT

University of Tokyo is now planning to construct a new 6.5m telescope on a peak at Chajnantor region of Atacama, Chile. This project is called "Tokyo Atacama Observatory"(TAO), and the site testing is now under progress. As a part of this site testing, we have developed a portable DIMM system which is called a "University of Tokyo DIMM" (UT-DIMM) to measure seeing. The system is mostly consisted of inexpensive commercial products, which are a MEADE 12 inch telescope, video-rate CCD camera with an electronic shutter, a Linux based PC, and so on. It has thrifty power consumption and can be operated for one whole night only with a single DC-12V battery for an automobile. In this paper, we describe the instrument, report the current status, and explain its future plans.

Keywords: site testing, seeing, atmosphere, DIMM

1. INTRODUCTION

University of Tokyo has a plan to construct a 6.5m telescope optimized to the near- to mid-infrared wavelength on a peak at Chajnantor Region of Atacama desert in Chile, which is at very high altitude above 5600 m. It is called "Tokyo Atacama Observatory" (TAO) project.[1]

The site selection started with a pre-selection procedure using satellite data, which is a collaborative work with CTIO.[2] The results suggest that the region around Co. Chajnantor is the best site from a view of perceptive water vapor, although it has rather higher cloud coverage than the best site such as Co. Paranal and Co. Quimal. However, because this analysis is based on atmospheric models and low resolution images of satellites, we have to confirm it by measuring the local weather on site. Also, seeing cannot be measured from the satellite data. We have therefore started a survey to measure the local condition around Chajnantor region.

As a part of this survey, measurements of seeing were planned, and a development of a seeing monitor with a concept of "Portable and Cheap" started. We have employed the differential image motion monitor (DIMM) system, which is now broadly used for site testing over the world.

It is composed of commercial products such as a telescope for amateurs, a video-rate CCD camera, and a Linux-based PC. All the components can be driven by a single DC-12V battery for an automobile, so it can be operated anywhere, even at a site where AC power-supply is unavailable. We call this system a "University of Tokyo DIMM" (UT-DIMM).

We describe the whole system in section 2, report the results of test observations carried out at Atacama and Manua Kea in section 3, explain the future plan in section 4, and summarize them in section 5.

Send correspondence to K.M.: E-mail: kmotohara@ioa.s.u-tokyo.ac.jp,
Telephone: +81-422-34-5049, Fax: +81-422-34-5041

2. INSTRUMENTS

2.1. System Overview

Figure 1 describes the overview of the UT-DIMM system, and table 1 summarizes the specifications. It consists of a commercial telescope for amateurs with a mask which has four apertures, a video-rate CCD camera, a Linux-based PC with a video capture board, and a DC battery for power supply. We have manufactured two sets of the system, and currently one is at Atacama and the other is at Mauna Kea.

2.2. Telescope and CCD

The telescope is a 12-inch Schmidt-Cassegrain, manufactured by MEADE Co. Unlike a "classical" DIMM with two apertures, the UT-DIMM has four apertures. This is because we expect that wind information of a turbulence layer can be measured from the seeing values obtained from two orthogonal pairs of the apertures, using the effect of wind speed and direction to the measured seeing value.[3,4] A mask plate with four apertures is installed at the front of the telescope-tube, and wedge-prisms with an apex angle of $40''$ are installed on each aperture. The size of the aperture is 74mm in diameter, and the separation of diagonal apertures is 205mm. Rays from a star are refracted by four wedges in the apertures and make four stellar image on the CCD (figure 2).

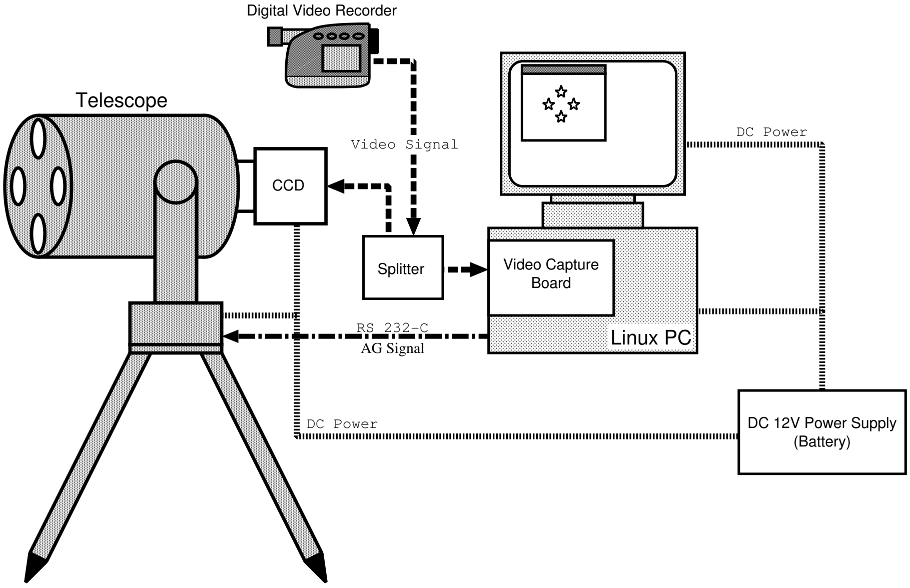

Figure 1. System overview of the UT-DIMM.

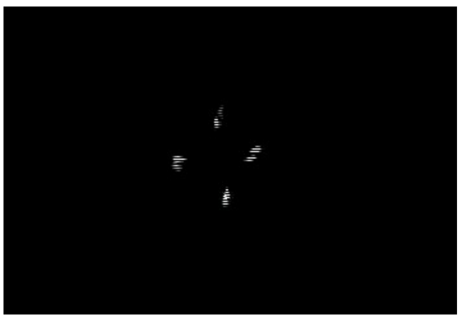

Figure 2. A stellar image taken by the UT-DIMM.

Aperture diameter	74 mm ϕ
Aperture separation	205 mm (diagonal line)
Number of apertures	4
Pixel scale	$0.''67$/pix $\times$ $0.''63$/pix
Effective wavelength	5500Å
Limiting magnitude	$\sim$ 1.5 mag (1 ms exposure)

Table 1. Specification of the UT-DIMM

The CCD camera is a low readout-noise model manufactured by Watec Co., Ltd. Output is an analog video signal, and gain is adjustable. It has an electronic shutter which enables us to vary the exposure time from 10 μs to 17ms.

The pixel scale was measured from images of a binary star β Cyg, and found to be $0.''67$/pix for the horizontal axis and $0.''63$/pix for the vertical axis.

2.3. Data Acquisition Computer

One of the problems for site testing is that there is usually no electricity available. We therefore have to carry a power supply together. While power consumption of a telescope and a CCD camera is usually enough low for a single battery to drive them for a night, a PC for data-acquisition(DAQ) usually requires much more power. Then, there are basically two choices for a combination of a PC and a power supply.

One choice is to employ a laptop PC with a video capture card in a PCMCIA slot. However, even using the latest model, a battery for a laptop PC doesn't have enough capacity to it for even a single night. Therefore, several extra batteries are necessary for observations. Also, most of the vendors of such capture cards don't provide a library for software programming, and only limited products are available for our system. In addition, there are usually no compatibility between such libraries so we have to re-write the software whenever we change a capture card to another model.

The other choice is to use a power-consuming desktop PC with a PCI-bus based video capture card, driven by a portable power generator. This method has an advantage of introducing Linux as an operating system and using a driver/library called "Video for Linux" (V4L), which can drive many of available PCI capture cards. Another advantage of using V4L is that once we write a software, we can use it for any capture board, because the V4L driver/library hides all the differences of the hardware. However, this method has a disadvantage of carrying a rather heavy ($\sim$100 kg) power generator and handling it at altitude of 5600m.

Finally, we found eclectic solution employing a x86 platform EIPA-E533 of VIA Technologies, INC., based on Eden ESP5000 CPU. Power requirement for this platform is as low as 20W, compared to that of Pentium III system of $\sim$100W. We combined this mother-board with a case which has a power unit that can be driven by DC 12V. The total power consumption is measured to be maximum 36 W during a boot process, 18 W at idling, and 22 W during data acquisition. This means that we can drive the whole system for few nights using a lead battery for an automobile, whose capacity is usually over 1000 Wh.

2.4. Software

Structure of the data-acquisition software is shown in figure 3, which consists of a single process. A captured frame is handed to the process by the V4L library. Centers of gravity (COGs) are measured in each frame, seeings are calculated for every 120 frames, and results are written into a file. The acquired frames and the positions of COGs can be displayed on the screen using Open GL library. However, because it uses quite much of CPU power to display all frames, only positions of COGs are displayed in normal operation.

The time variation of seeing saved in the file is plotted using gnuplot. Plot is refreshed by a trigger issued from the main process. Also, still a preliminary function, the telescope can be controlled from this process via

RS-232C interface. This will be used for auto-guiding and auto-acquisition of a star, which will be an important function for fully automated operation.

There are several choices of combination to calculate standard deviation σ of the relative position of stellar images from the four COGs. We have chosen two diagonal combinations for calculation, which are the stellar images of the horizontal and vertical pair. For the measurement of COGs, we cannot use a full frame ecause

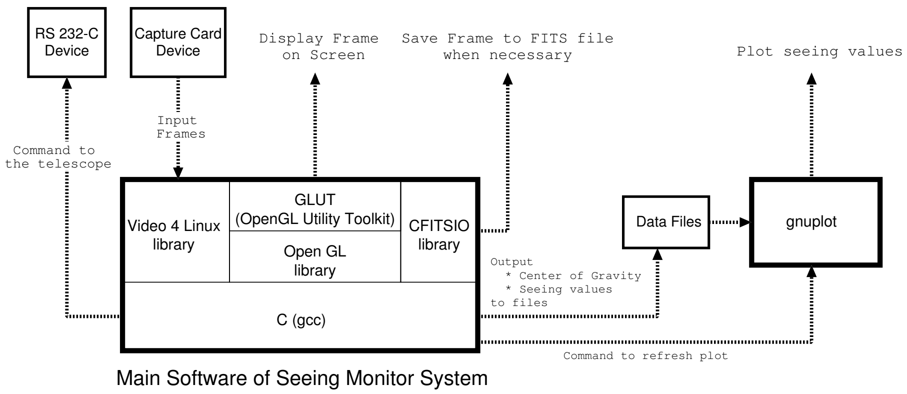

Figure 3. Block diagram of the software of the UT-DIMM.

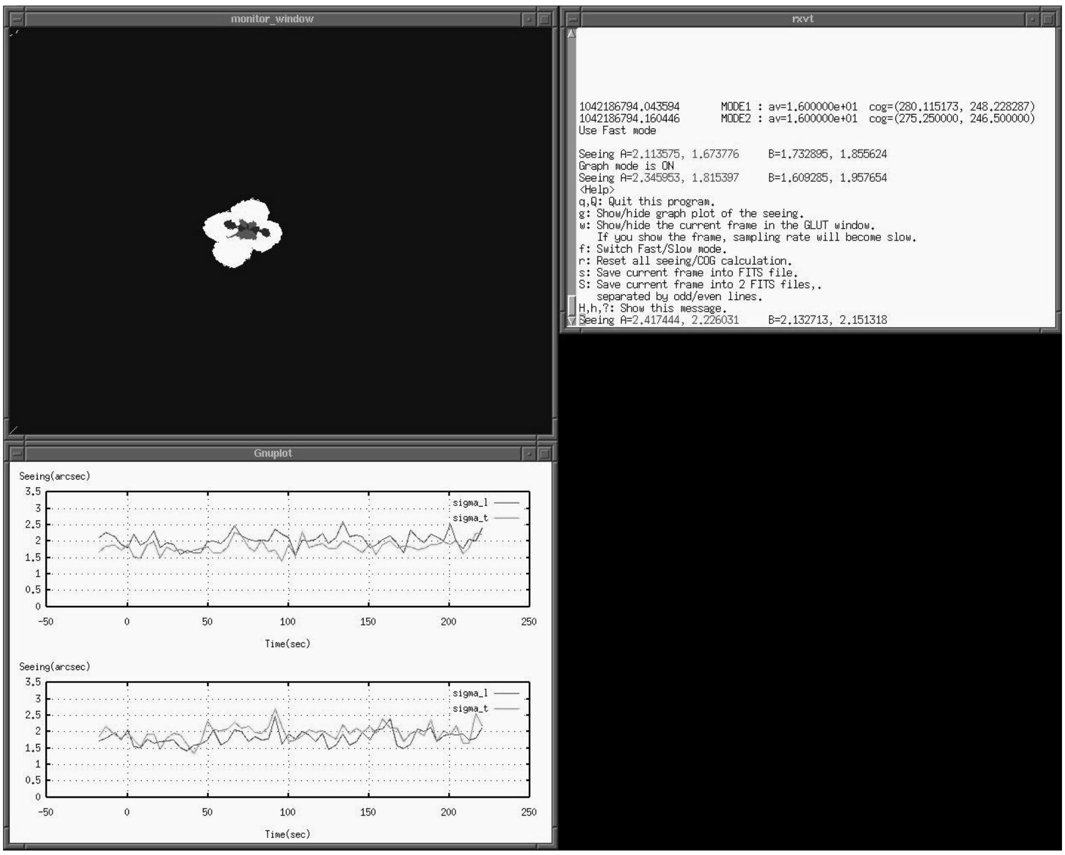

Figure 4. Screen shot of the seeing monitor software. Upper-left is a window to display captured frames and positions of COGs, lower-left is a plot of seeing, and upper-right is a console window.

a frame from the CCD camera is an interlaced image of two scans separated by 17 msec. Instead, COGs are calculated separately in frames of even rows and odd rows. Then, σ are calculated for each sets and averaged values are returned. The conversion of σ to seeing value is done using the formula given by Sarazin & Roddier.[5]

The frame rate is measure to be ∼13 frames/sec in our system, which is limited by the CPU power of the PC, and if we run this software on a more powerful PC, a full-frame acquisition (30 frames/sec) becomes possible.

3. OBSERVATIONS

3.1. Test Observations at Atacama

To check an operation at Atacama desert, we have performed test observations from November 30, 2002 to December 4, 2002.

The observations were carried out at 2 sites; one is at a saddle point between Co. Chajnantor and Co. Chascon, where the altitude is 4950m according to GPS. The other is at a site of Atacama Submillimeter Telescope Experiment (ASTE) which is operated by National Astronomical Observatory of Japan, and the altitude is 4840m. These locations are shown in figure 5.

It was confirmed that the whole system works well without any trouble. However, due to a bad weather caused by approach of rainy season so-called "Bolivian winter", only 5 hours of data was obtained. In addition, because of a mis-operation, the whole data was taken with 17ms exposure instead of 1∼2 ms. This resulted in elongation of stellar images due to vibration of the telescope by strong wind, and also in missing of motion with higher frequency which will result in better seeing than real value.[3]

Histograms of the seeing is shown in figure 6. The measured seeing was $0.''8$ - $1.''8$. If we assume the wind speed to be 20 m/s, these values are expected to be underestimated by a factor of 1.5–2[4] .

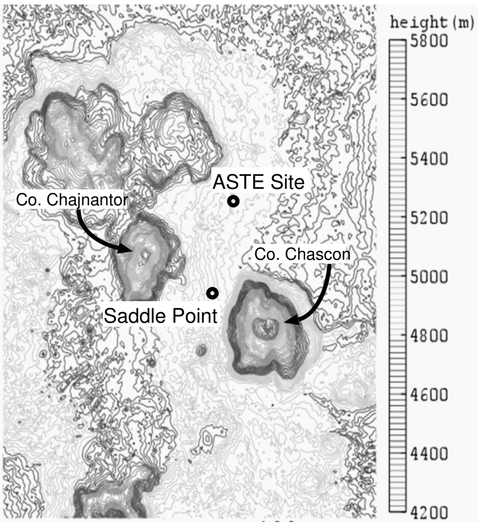

Figure 5. Map of Atacama site. The open circles show the locations of the seeing observations.

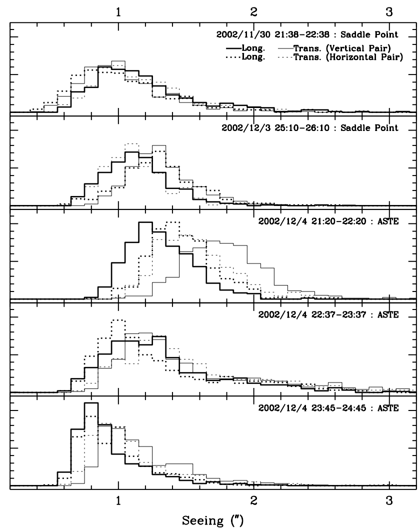

Figure 6. Histograms of the observed seeing during the test observations at Atacama. The solid lines show the seeing obtained from the vertical pair of the aperture, and the dotted lines from the horizontal pair. The thick and thin lines represent the data from longitudinal and transverse motions, respectively.

3.2. Test Observations at Mauna Kea

For a calibration of the UT-DIMM, simultaneous observing runs with the DIMM of the Subaru telescope (Subaru-DIMM)[6] were carried out at the summit of Mauna Kea on March 18 and 19, 2003. The height of the apertures

Figure 7. Calibration observation of the UT-DIMM (left) with the Subaru-DIMM (right) at Mauna Kea.

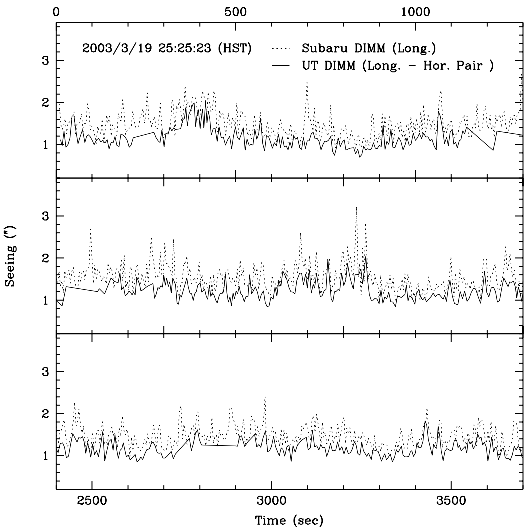

Figure 8. Example of a comparison of measured seeing between the UT-DIMM (solid lines) and the Subaru-DIMM (dotted lines) at Mauna Kea, which are taken on the night of March 19, 2003 (HST). Both plots are calculated from the longitudinal motions, and the stellar images of the horizontal pair of the apertures are used for measurements of the UT-DIMM.

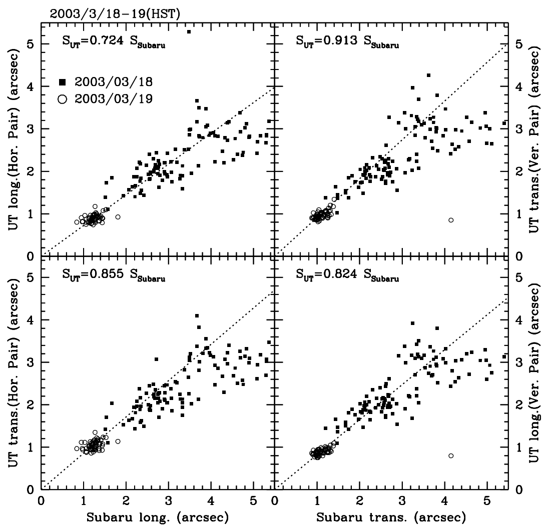

Figure 9. Correlation of the seeing value between the UT-DIMM and the Subaru-DIMM. The left two boxes are the correlations between the seeing from longitudinal motions of the Subaru-DIMM and that from the corresponding motion of the UT-DIMM, which is the longitudinal motions of the horizontal pair of the apertures and the transverse motions of the vertical pair. The right two boxes are the correlations between the seeing from transverse motions of the Subaru-DIMM and that from the UT-DIMM. The filled squares are the data taken on March 18, and the open circles on March 19. The dotted lines are the results of linear fits to the points, and fitted equations are shown in upper-left of each graph.

was adjusted to the same level, to cancel out the difference of the turbulence caused by the ground layer (figure 7).

Variation patterns of seeing match well each other as shown in figure 8, but the measured value of the UT-DIMM is systematically smaller than that of the Subaru-DIMM. We show the correlation of the seeing data between the UT-DIMM and the Subaru-DIMM in figure 9. The measurements of the UT-DIMM are $10-20\%$ smaller than that of the Subaru-DIMM.

However, it is found that this difference will be decreased to $\sim 10\%$ if the pixel size to measure the COGs of the Subaru-DIMM is reduced from 50×50 pixels to 9×9 pixels. Therefore, we conclude that some fraction of the offset must have been caused by the rather high readout noise[7] of the Subaru-DIMM's CCDs. Then, about the remaining difference, it may be caused by systematic difference of condition because no difference in the seeing size were observed during other simultaneous observations carried out in July (Uraguchi, private communication).

4. FUTURE PLAN

Our final goal is to carry out seeing observations at summits of some peaks at Chajnantor region for some timescale ($\sim$ a month). It is difficult to carry out manned seeing observation at such high altitude, due to low atmospheric pressure and low temperature. Therefore, our final goal of the development is the automation of the whole system.

Functions required for unmanned operation are

- auto-guiding
- scheduler for selecting stars
- auto-focusing.

The function of auto-guiding is now under development. It uses the acquired frames, and the telescope is controlled via RS-232C interface. A preliminary version of the software is now being tested.

5. SUMMARY

We have developed a portable DIMM system (UT-DIMM) for site survey of the TAO telescope project at Atacama, Chile. The whole system consists of inexpensive commercial products, and can be driven by a battery for an automobile for a night.

We have carried out test observations at Atacama, and confirmed the operation of the system. The measured seeing value was $0.''8$ - $1.''8$, but it may be underestimated by a factor of ~ 2 due to the long exposure time of 17 ms. Other observations at Mauna Kea were also done to check the correlation of seeing value with that of the Subaru-DIMM. It was confirmed that the shape of the time variation correlated well, but the UT-DIMM returns smaller seeing than that of the Subaru-DIMM by a factor of $10-20\%$. Some of the offset is found to be produced by the rather high readout noise of the Subaru-DIMM, and the remaining must have been caused by unequal condition of the measurement, because no offset were observed during another observing run in July.

Our future plan is to upgrade our system so that automatic observations become possible, and to bring it to the summits of some peaks at Chajnantor region at Atacama.

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