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Astronomical Seeing Measurement of two Observatory Sites in Malaysia: The DIMM Method

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ABSTRACT A low cost differential image motion monitor (DIMM), consisting of a 12-inch Meade, an STV Santa Barbara Instrument Group (SBIG) auto guiding CCD camera and a notebook is described. The system was used for seeing measurements in Kuala Lumpur on August 2002 and January 2003, also in Merang, Trengganu on March 2003. The preliminary results of these measurement show that the seeing value in Kuala Lumpur is greater than 2 arcseconds. Seeing value in Merang is about 1 arcsecond. Merang however, has better seeing than Kuala Lumpur. Kuala Lumpur has slightly worse seeing (>3 arcseconds) compared to Merang.

ABSTRAK Pantau gerakan imej pembezaan (DIMM) kos rendah terdiri dari teleskop 12-inci, system kamera CCD STV Santa Barbara Instrument Group (SBIG) dan sebuah computer. Sistem ini digunakan untuk mengukur kenampakkan (seeing) di Kuala Lumpur pada Ogos 2002 dan Januari 2003, dan di Merang, Terengganu pada Mac 2003. Hasil pengukuran awal menunjukkan nilai kenampakkan di Kuala Lumpur adalah di antara 1 ke lebih besar dari 2 arkasaat manakala Merang adalah lebih kurang 1 arkasaat sedikit lebih baik berbanding di Kuala Lumpur bermakna Merang mempunyai langit yang lebih baik berbanding Kuala Lumpur untuk tujuan cerapan astronomi.

(Seeing, differential image, turbulent, scattering, interferometer)

INTRODUCTION

Astronomical seeing is a well-known quantity that can be hard to quantify. It is usually expressed as the angular diameter, ε_{FWHM} of a star image (in arcsec) at the focus of a telescope taken with long exposure [1] and is a broad term that describes the condition of the night sky and how suitable it is for astronomical observation. This seeing effect is caused by the high frequency temperature fluctuations associated with atmospheric turbulence through which some of the incoming starlight is scattered by refractive inhomogeneity [2]. As the light wave propagates through the atmosphere, it experiences fluctuations in amplitude and phase. Consequently, when the perturbed incoming light wavefront is focused, the resulting star image exhibits variation in intensity, sharpness and position which are referred to as scintillation, image blurring and image motion. In measuring astronomical seeing, many different attempts have been made since the pioneering work by Rosch (1963) [3]. Although the parameter relevant to image degradation is related to geophysics (turbulent fluctuations of air density), all seeing monitors are optical instruments: balloon data (Vernin and Munoz-Tunon, 1992, 1994) can be used to estimate ε_{FWHM} but cannot monitor it versus time. Different concepts have been used: Visual method (Shevchenko, 1973), Danjon method, Polaris trail, shearing interferometer (Roddier, 1976), Scidar technique (Azouit and Vernin 1980), photoelectric instruments (Shcheglov, 1984), DIMM (Stock and Keller, 1960 & Sarazin and Roddier, 1990) and Grating Scale Monitor (GSM) (Martin *et al.* 1994). They used different receivers such as eyes, photographic plates, photomultipliers or intensified CCDs.

The Principle of DIMM Method

Despite several methods introduced to measure astronomical seeing, the Differential Motion

Monitor (DIMM) is accepted as the most accurate, reliable and simple method for evaluating qualitative and quantitative astronomical seeing. M. Sarazin and F. Roddier (1990) first developed it at the European Southern Observatory (ESO). This technique was then adapted by many well known observatories like ING DIMM at La Palma Observatory (1994), Robo DIMM at Cerro Tololo Inter-American Observatory (1995), DA/IAC DIMM at the Observatorio del Roque de Los Muchachos (1997) and DIMM at Skinakas Observatory (2001).

According to Fried's theory (1966) [3], image degradation produced by atmospheric turbulence is characterized by the r_0 parameter which can be imagined as the telescope diameter that would produce a diffraction spot of the same size as that produced by the atmospheric turbulence on a point source observed with an infinite mirror. The DIMM measures the strength of the aberrations due to atmospheric turbulence and then predicts the seeing, ε_{FWHM} for a large telescope assuming the standard seeing model. The aberration strength is defined by Fried's parameter r_0 [4]. Small values of r_0 indicate strong turbulence and hence poor seeing.

The principle of the DIMM is to measure the variance of the differential centroid motion for images of a star produced separately from two apertures of known separation within the entrance pupil of a telescope. The differential image motion is unaffected by tracking errors or telescope vibration or by small focus error and so gives an unbiased estimate of the image degradation due to the free atmosphere alone. The idea is that the incoming starlight passing through the two apertures, travels through slightly different atmospheric conditions producing a tilt in the wavefront of one compared to the other [5]. Hence a slight variation resulted in the separation of the two images. The relationship between ε_{FWHM} and r_0 can be written as

$$\varepsilon_{FWHM} = 0.98\,\lambda / r_0 \qquad (1)$$

for $r_0 << D$.

To estimate the Fried's parameter r_0, one can measure the variance, σ^2, of the two dimensional image position through a single aperture of diameter D.

$$\sigma^2 = 0.373\,\varepsilon^2_{FWHM}\,(r_0 / D)^{1/3} \qquad (2)$$

By measuring the image motion at the telescope focus with known aperture D and wavelength λ, the Fried's parameter r_0 and the seeing can be deduced. The variance and the Fried's parameter are related by [6];

$$\sigma^2 = 0.358\,(\lambda / r_0)^{5/3}\,(\lambda / D)^{1/3} \qquad (3)$$

The typical values of Fried's parameter are $r_0 = 10cm$ for $\lambda = 0.55\,\mu m$ and $r_0 = 25cm$ for $\lambda = 1.20\,\mu m$. Hence, r_0 increases with wavelength.

INSTRUMENTATION AND MEASUREMENT TECHNIQUE

In order to provide a transportable and easy to operate instrumentation for measuring astronomical seeing condition, one can use a small reflector telescope. Instrumentation for DIMM system at our research laboratory consists of a Meade LX200 12" telescope, Santa Barbara Instrumentation Group stand alone video (SBIG) STV CCD camera as the detector, a two circular holes cardboard mask, a laptop computer, thermometer, barometer and hygrometer.

A cardboard mask is made of two circular holes at 80% of the diameter of the telescope aperture apart, each 20% of the diameter of the telescope aperture [7]. In our case, the hole diameter was 2.4" (6.1cm) and centre to centre of the two holes separation was 9.6" (24.4cm) as shown in Figure 1.

The measurement is carried out by pointing the telescope to a bright star near the zenith (zenithal angle $\leq 30^0$) and imaging it with the SBIG STV camera. The mask was placed over the telescope aperture and the telescope defocused to get two spots cleanly separated but not so defocused to avoid blurry star images. Then, the mask was oriented so the star's images are horizontally separated on the CCD. By using SBIG STV seeing monitor mode, the DIMM seeing software will automatically carry out the measurement and report the seeing as FWHM (in arcsec) of a long exposure stellar image (5 to 10 seconds). It uses the rms relative motion of 32 images to calculate the result. An example of the displayed 3-D graph and its alphanumeric display is shown in Figure 2.

The 3-D images show how the two images move relative to each other while the graph exhibit stellar profile and report the seeing as the full width half maximum in arcseconds.

The mathematics behind the displayed value was principally based on the principle of DIMM method that correlates the FWHM and R_o values;

$$\mathrm{FWHM} = 0.98 \times \lambda / (4.85 \times 10^{-6} \times R_o) \qquad (4)$$

where λ is wavelength in cm (0.00006) since that STV has a V-filter inside the camera head, and R_o is the atmospheric cell size in cm, the transverse phase coherence length (the Fried parameter). R_o is related to the rms differential image motion by:

$$R_o = \{\mathrm{rms}^2/[2 \times \lambda^2\,(0.179d^{-1/3} - 0.0968 \times r^{-1/3})]\}^{-3/5} \qquad (5)$$

Where d is diameter of individual aperture in cm, R_o is separation of apertures in cm and rms is standard deviation of spot separation in cm [6].

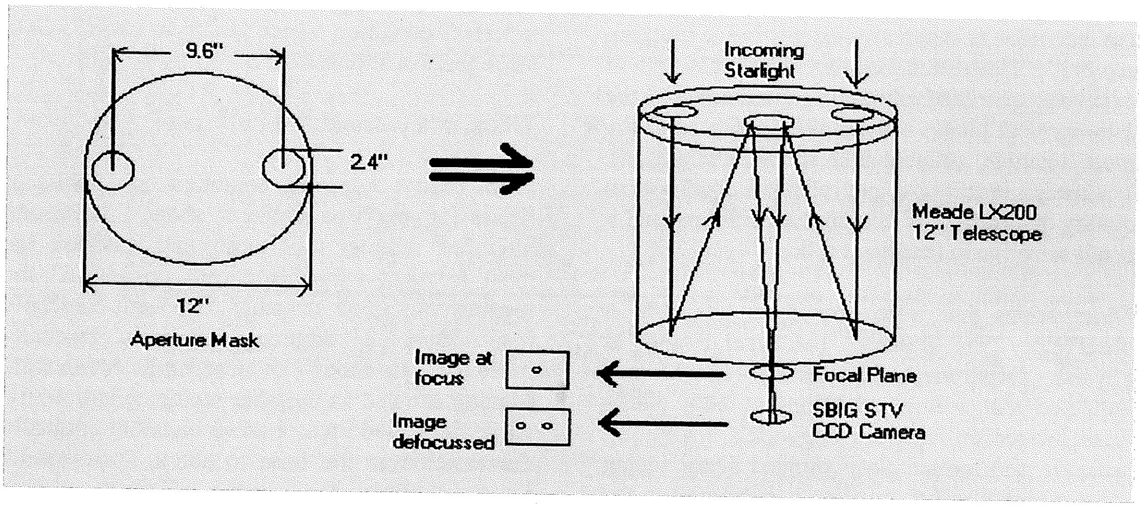
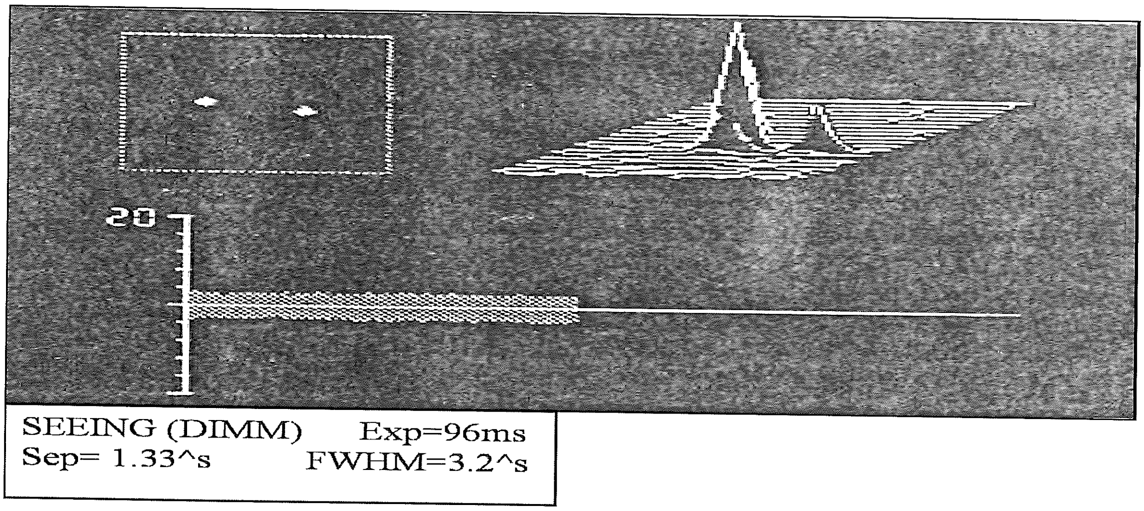


Figure 1. Two holes mask for DIMM configuration



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SEEING (DIMM)      Exp=96ms
Sep= 1.33^s        FWHM=3.2^s
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Figure 2. 3-D graph and alphanumeric display

Table 1. Scale of Astronomical Seeing

SCALE	T-VALUE	DESCRIPTION
I	$t > 1.5a$	Image tending towards a planetary appearance.
II	$t = a$	Strong turbulence; rings weak or absent.
III	$t = 0.5a$	Medium turbulence, diffraction rings broken, central spot having undulating edges.
IV	$t = 0.25a$	Complete rings crossed by moving ripples
V	$t = < 0.25$	Perfect images without visible distortion and little agitated.

RESULTS AND DISCUSSION

DIMM method consists of measuring wavefront slope differences over two small pupils some distance apart. Because it is a differential method, the technique is inherently insensitive to tracking errors [7]. This technique is an efficient system to evaluate quantitatively and qualitatively the astronomical seeing and has been accepted as the most accurate, reliable and simple method [6]. The measurement does not require a good optical quality or a particular telescope size or lens and it is not sensitive to tracking motion.

Observations that were carried out at KUSZA observatory in Merang, Terengganu and at Physics Department, University of Malaya indicated that seeing conditions at both places were limited at scale I (Sidgwick's scale) [8], however, the former place showed better seeing value which was 1.5 arcseconds compared to the latter one which was 2.2 arcseconds. Seeing condition is represented in FWHM value, an average value that was taken from about 2230 to 0400. Scale I in Sidgwick's scale, Table 1, described the image tending towards a planetary appearance and scale V is the highest scale shows a perfect condition which is almost unobtainable since there is atmosphere covering the earth.

Where a (arcsecond) = 140/D (mm)

From Figure 3, seeing condition on 11/8/02 in Kuala Lumpur was stable at about 1 arcsecond after few minutes monitoring and was also the most frequent value. However, on 13/1/03 the reading was quite unstable, the value suddenly rose above 3 arcseconds before gradually decreasing to about 1.5 arcseconds. Meanwhile Merang showed an unstable seeing condition, the value fluctuated up to 4 arcseconds but gradually decreased over the time to about 1 arcsecond. Figure 4 shows the number of all the seeing values recorded.

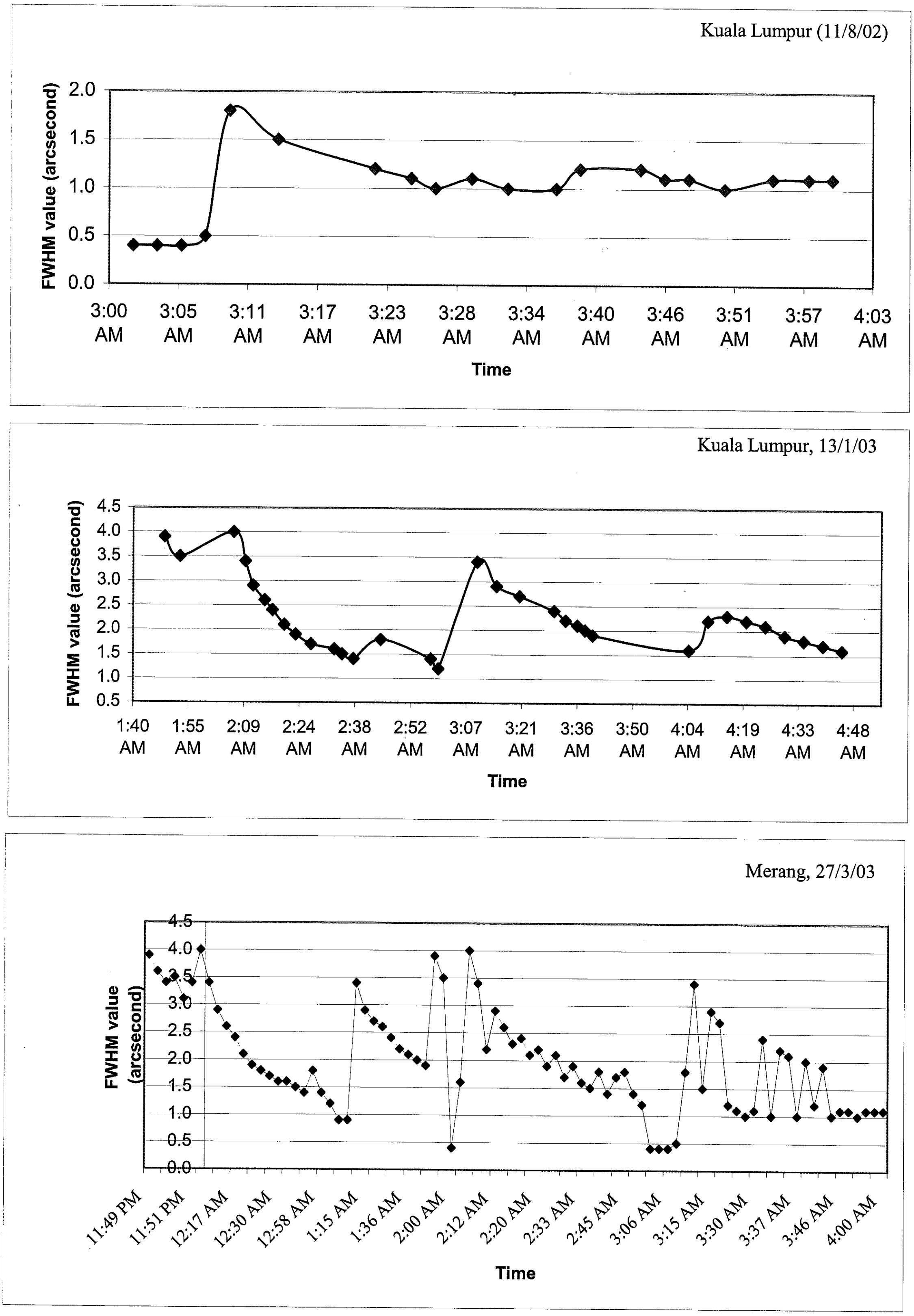
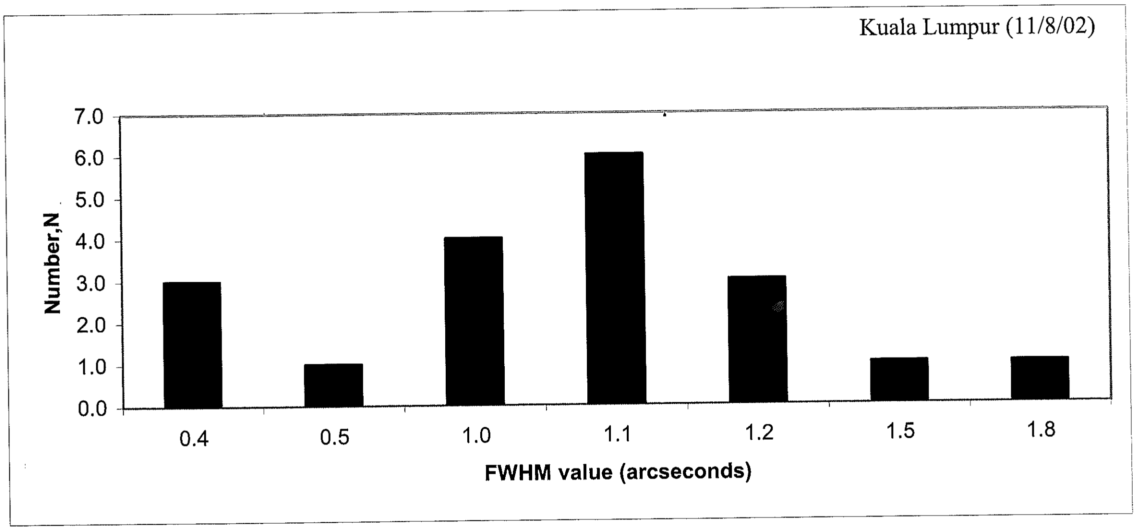
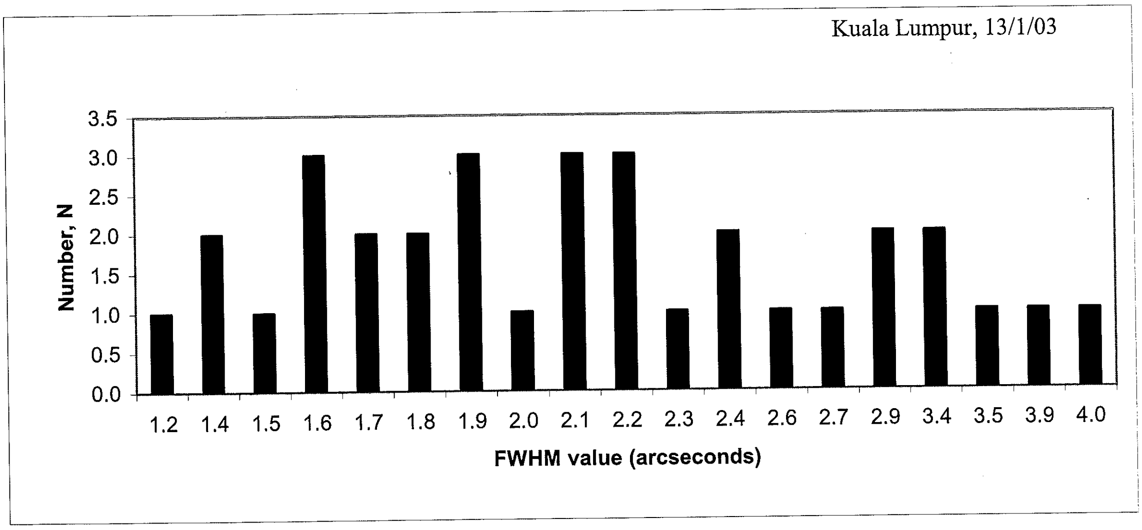


Figure 3. Time dependence of seeing measurements done with DIMM at different location sites namely Merang and Kuala Lumpur





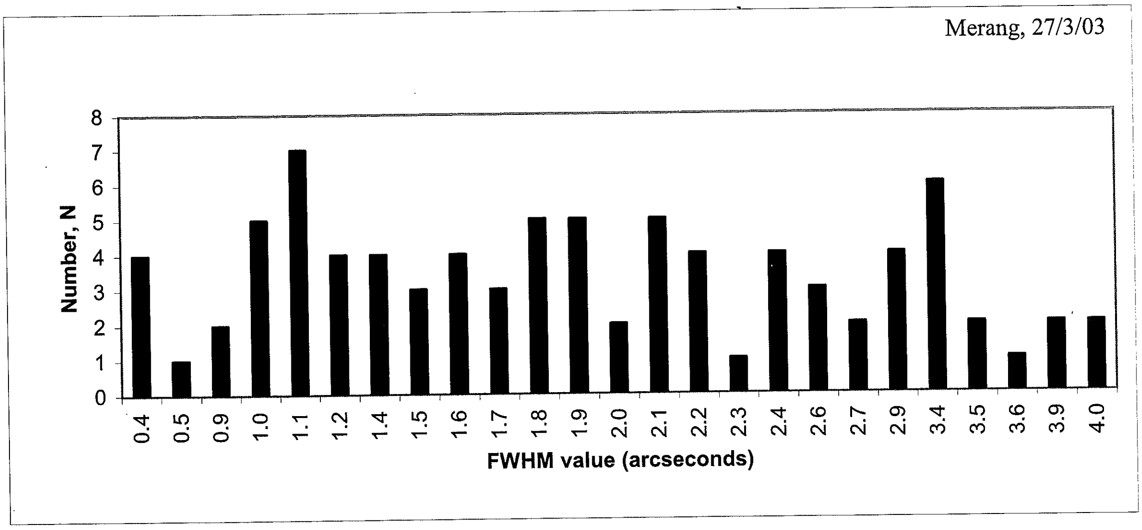


Figure 4. Number of FWHM values measured at all the preferred sites.

CONCLUSION

Seeing condition however defined by averages of the nights values measured indicated Kuala Lumpur (11/8/02) and (13/1/03) had 1.2 arcseconds and 2.3 arcseconds respectively, and Merang (27/3/03) had 1.5 arcseconds. Supposedly, Merang had better seeing than Kuala Lumpur due to less pollution caused by street lights and air [2]. It should be noted that in March, the weather was still windy thus several types of particles and dust materials maybe circulating at lower altitudes. These particles store heat and will cause thermal air currents that might affect the seeing condition [2].

The measurement should be done schematically to evaluate the suitability of observation sites and also to seek for a new one. Therefore, a database of seeing conditions in Malaysia can be setup for future reference. Based on the results, we can identify the factors that may influence the seeing level and the atmospheric turbulence. This information is valuable for studying the local atmospheric phenomena profoundly and the impact on the development of astronomical research in Malaysia.

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