RoboDIMM — The ING's New Seeing Monitor

Neil O'Mahony (ING)

A brand new dome stands near the William Herschel Telescope, its white surface reflecting the strong mountain sunshine. Inside is ING's automatic seeing monitor, RoboDIMM, which became operational in August last year. What was announced as a project in the March 2001 *ING Newsletter*, **4**, 27, in an article by Thomas Augusteijn, is now a fully functioning reality.

Figure 1 (left). RoboDIMM stands ready at sunset for a night's observation at the Roque de Los Muchachos observatory. The dome is opened remotely from the WHT control room and the automatic observing program is started. The tower, 5 m tall, is located about 75 m north of the dome of the William Herschel Telescope, on a gentle slope facing unobstructedly the prevailing winds.

Figure 2 (right). The RoboDIMM telescope at polar park position, with the WHT in the background. The entrance aperture forms 4 separate images of the same star (the large central aperture is no longer used). The sub-apertures, covered by optical wedges, are aligned along N/S and E/W (despite what the perspective here may suggest). Both photos by R. Gorter of Startel.

The Differential Image Motion Monitor, proposed by Sarazin and Roddier (1990, *A&A*, **227**, 294) and based on a small telescope and relatively inexpensive equipment, has over the last 10 years become the most common seeing measurement method used in site testing and characterisation. Nowadays, whether for control of image quality or to help decision making in queue scheduling, DIMM-type seeing monitors have become an indispensable tool in observatories around the world. The seeing has become just one more "meteorological" datum that ground-based astronomy is expected to have at its fingertips.

This is why, in common with observatories in Chile and elsewhere, the ING chose to replace its DIMM (1994–1999) with a new "robotic" DIMM. ING's RoboDIMM now fulfills its projected function, which was to make reliable seeing measurements available throughout the night, requiring user intervention only for startup and shutdown, and controlled remotely from the WHT control room.

RoboDIMM started observing in August 2002, to coincide with the first NAOMI "science run" at the WHT. It sampled the seeing on 85 nights until December, missing only 20% of nights, mostly due to poor weather. Around this time, a fault with a telescope drive motor began causing significant down-time. Now the motor has been replaced and RoboDIMM again accompanied the NAOMI run of April 2003. It has continued in its routine job of seeing monitoring throughout last summer without pause.

Installed atop a 5 m tall tower (see Figure 1), which it inherited from the previous DIMM installation, RoboDIMM is built out of a combination of off-the-shelf hardware items, with the vital addition of custom-made software.

The main commercially available components are a Meade 12″ Schmidt-Cassegrain telescope (LX200 model), an ST-5C CCD from Santa Barbara Instruments (SBIG), and a 12′ diameter (3.7 metre) dome with motorised opening supplied by Astrohaven in Canada. The other vital component, a mask that goes over the telescope entrance aperture, was machined in-house, to which some specially ordered small-deviation prisms ('optical wedges') were added.

It is worth mentioning some special properties of the tower, designed by Dario Mancini of Capodimonte Observatory and used elsewhere at ORM and at ESO's Paranal Observatory. It consists of a vibration-proof central truss, 5.2 m tall, upon which the telescope is mounted, and a second tower that surrounds it and supports an "access platform". In the case of RoboDIMM the latter has been slightly widened to house the dome. The two structures are mechanically independent, so that the telescope is isolated from vibration caused by wind buffeting of the dome. When fully open, the dome presents a 1.5 m-high barrier to the wind, from which the telescope stands proud. Since ground layer heating is significantly reduced at the height of the tower, we assume that the dome induces minimal optical turbulence and has insignificant effect on the DIMM measurements. The support struts allow the wind to flow around them, and louvered ports in the dome floor open automatically, improving vertical airflow.

The control software was written for ING by Startel Ltd., in the Netherlands (www.startel.nl (Dutch language), www.robodimm.com (in construction)). It is a C++ program, running on a Linux-based PC, and controls all relevant automatic functions: from choosing suitable targets and acquiring them, to controlling the CCD, processing measurements and writing them to a database. The telescope is commanded through a serial port connection to the PC, exploiting a feature of the Meade LX200. The program runs a continuous sequence of tasks but also allows user intervention and control of status and data quality through a graphical interface.

Operation

At present the dome must be opened and closed by ING personnel, formally the WHT Telescope Operator, from the control room of the WHT. This may be automated in the future, and the upgrade to the telemetry system that this would require is being considered. We may then be able to implement automatic closure in response to adverse weather conditions.

The control program can be left running permanently, because it automatically stops observing at sunrise and will automatically start again around the following sunset, depending on the brightness of available targets. This lightens the workload on the TO at the beginning of the night and helps to provide an early seeing estimate, sometimes even before the sun has gone down! Such an early estimate has clear applications in queue observing. If a seeing measurement is available over the previous 5 minutes, it is published on the ING Weather Station Web page, (www.ing.iac.es/ds/weather/). A graph of the night's data is also publicly available (at night time) through the Weather Page, as is the full set of archived data (or see http://www.ing.iac.es/ds/robodimm/).

The chosen target is the brightest available star within 30 degrees of the zenith, in a magnitude range of 2 to 4, although brighter stars can be used in cloudy conditions. The acquisition field is almost 4×3 arc minutes, but if no star is found in the first CCD image taken at the target position, the program starts a search spiral. In clear conditions this usually results in a successful acquisition within a few minutes. Once the star is near enough to the centre of the CCD, the pointing offset of the telescope is updated, the readout is windowed and a series of 200 images with 10 ms exposure is taken. After this, there is a brief pause while the standard deviation of the images' relative positions is measured and the FWHM is calculated from this. The program then repeats the sampling and measurement cycle to provide continuous monitoring, moving to a new star when the observing elevation goes below 60 degrees.

A seeing measurement is made at irregular intervals of approximately 2.5 minutes, and most of that time is spent taking the 200 images in the sample. This is a much longer duty cycle than the original ING DIMM, but it may be possible to speed this up in future by customising the firmware on the CCD controller. We estimate a further 20% of operative time for which no measurement is available due to miscellaneous overheads, which may be improved upon. The software is now fully functional with small improvements continually being added, in close collaboration with the software authors, Startel.

Interpretation

RoboDIMM forms 4 images of the same star (see Figure 2), measuring image motion in two orthogonal directions from each of the two pairs of images, from which it derives 4 simultaneous and independent estimates of the seeing. When the system is correctly set up, these 4 measurements should agree, over a reasonably sized sample. We find that relative sizes vary from night to night and show a noticeable sensitivity to the focus position of the Meade telescope, which has been observed to flop after a telescope slew. At present the focus has to be adjusted by user command using an electronic focuser mounted above the CCD, but we are investigating whether to fix the focus mechanically or make automatic adjustments in the future.

The measurement published on the Weather Page is the average of 4 simultaneous database entries, and users should be aware that this page is compiled using data from up to 5 minutes prior to the posted time. Up-to-date and individual measurements can be viewed by following the 'Seeing' link on the Weather Page. The database values are automatically corrected for the observing zenith distance (dividing by airmass to the power 3/5) and a wavelength of 550 nm and the time listed is that at the middle of the sample. The four instantaneous values can differ by, say, 20%, but what matters is that there should be no significant long term difference.

The general impression is that the average seeing published on the Weather Page agrees reasonably well with seeing being obtained at the William Herschel Telescope, including NAOMI and Richard Wilson's "Slodar" wave front sensors (see article on page 19), and with that obtained at other telescopes. It has shown sensitivity to all seeing conditions, registering averages as low as 0.35″ and (during the passing of a warm front) as high as 7″! A comparison with seeing data from the IAC DIMM (provided by the Sky Quality Group at the Instituto de Astrofísica de Canarias), using simultaneous samples of several hours length from 9 nights in October 2002, shows a 91% correlation (see Figure 3) between the seeing FWHM measurements made at the two instruments. The differences between the median values is scattered around $y=x$ by an amount varying between 3 and 15% on any given night, or about 8% on average. This average discrepancy is no larger than the internal error of either instrument.

The good agreement exists in spite of the large distance between the two monitors (several kilometres), the factor 10 difference between their sample duty cycles and their independent designs. Periods of rapidly fluctuating seeing were generally excluded from the samples used in this comparison, to avoid possible local effects.

While this result is encouraging and allows a good deal of confidence in RoboDIMM's seeing measurements, it is not conclusive, since no median below 0.6 arc seconds was used. Calibration of RoboDIMM is ongoing, including characterisation of intrinsic errors and comparison with other seeing monitors such as NAOMI's Wave Front Sensor.

As regards hardware components, ING's RoboDIMM bears a close resemblance to the CTIO's automatic seeing monitor (which, incidentally, is also called RoboDIMM, but the originality of that name is disputable! See `www.ctio.noao.edu/telescopes//dimm/dimm.html`). There is an important difference in that the CTIO's takes samples alternating between 5 and 10 ms exposure time. This forms two samples from which the image motion at "zero seconds exposure" is extrapolated, following the method established by ESO in its Chilean seeing monitors. The zero-second seeing may reportedly be 10–20% larger than the 10 ms estimate (A. Tokovinin, 2002, *PASP*, **114**, 1156), depending on the speed and altitude of turbulent layers. When comparing results from different sites, it is important to bear instrumental differences in mind but we should also remember that the strength of the exposure time "blurring" effect may differ greatly between sites, as well as vary over time.

Conclusion

With the commissioning of the RoboDIMM seeing monitor, ING has provided its Adaptive Optics programme with an important auxiliary instrument. It provides a seeing FWHM estimate at regular intervals that can be relied upon to within about 10% in stable conditions. RoboDIMM allows NAOMI performance to be monitored in real time, and also provides essential information for AO observing in queue mode. Additionally RoboDIMM provides all telescopes on site with data that can help astronomers to optimally adjust telescope and instrument focus. It allows them to make sure they are fully availing of the superb natural seeing available at the Observatorio del Roque de los Muchachos.¤

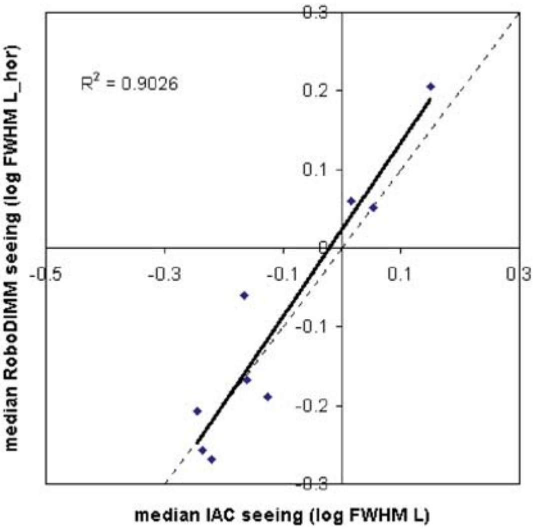

Figure 3. A scatter plot of the seeing FWHM measured by the IAC DIMM as a function of simultaneous RoboDIMM seeing. The best fit line, close to y=x, and the large correlation coefficient (0.91) illustrate the close dependence of these two variables. Each of the 9 points represents the median seeing from simultaneous samples formed by a continuous period of stable seeing lasting several hours. The logarithmic scale is necessary to convert seeing FWHM into an approximately normally distributed variable.

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CONCAM — ING's All-Sky Camera

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It has been a long-standing wish at the observatory to have a night-time all-sky cloud monitor. A cloud monitor, in the first place, allows astronomers in the control room to assess the actual situation of the night sky without the need of having to rush out for a visual check. The latter usually requires rushing up and down stairs, standing in the cold outside, and waiting for the eyes to get adapted to the dark, and even then one would only have a partial snapshot of the situation in the sky.

The ideal cloud monitor works at infrared wavelengths where the contrast between the cloudless night sky and the relatively warm clouds is high. However, a suitable infrared camera is rather complex and expensive to build, and as the equipment has to be located outside, there is a significant maintenance overhead as well. To avoid these problems we have been looking for an alternative for some time and came across CONCAM.

CONCAM stands for CONtinuous CAMera, designed and built by Robert Nemiroff and his team at Michigan Technical University. It is a well designed and built, self-contained system that only requires connecting to electrical power and the internet. CONCAM consists of a fish-eye lens that projects the night sky onto an SBIG CCD camera. The camera itself is controlled by a small notebook PC. The full system sits in a small, well-sealed weather tight box, located on the roof of the liquid nitrogen plant building, close to the junction of the road leading up to the WHT.

The camera switches itself on during evening twilight and stops at the end