NIWA360 solar tracker – 10 years on!

John Robinson, Bruno Kinoshita, Dan Smale and Alex Geddes

National Institute of Water & Atmospheric Research, Private Bag 50061, Omakau, New Zealand. Contact john.robinson@niwa.co.nz

Introduction

This roof-mounted instrument accurately tracks the sun, directing a stable image to the spectrometer (FTS) in the laboratory below.

The design has been in constant use since the prototype was installed in 2009. There are now three solar trackers in use at Lauder, and one at Arrival Heights, Antarctica. The four trackers are essentially identical. The basic design has proven stable and reliable. This 2019 poster presents a summary of the design, and an update on the previous 10 years development and performance.

A matching weather-proof autonomous cover is the subject of a further poster.

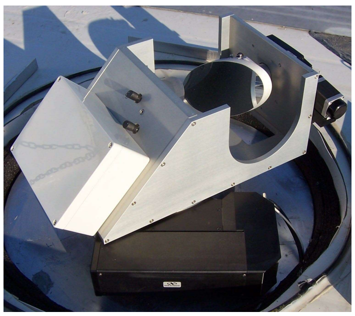

Figure 1. Solar tracker in use

Design philosophy and specifications

The specifications reflect the thinking behind the design, where the aim was to produce a simple, reliable and accurate solar tracker that would remain serviceable in the distant future.

- Modular design – to be easily upgradable for decades to come
- Few moving parts – no cables, switches or brushes to fail
- 360 degree continuous rotation – required in polar locations
- No daily re-parking needed
- Tracking is dead-reckoning, with optional optical feedback
- On-board GPS for time-keeping and location coordinates
- Versatile interfacing – Ethernet or serial
- Easy to align – optical feedback makes alignment less critical
- High resolution using micro-stepping (<0.002 deg.)
- High pointing accuracy (typically <+/- 0.02 deg.)
- Mirror size of 100mm as standard, but up to 148mm possible

Hardware

Precision rotator stages from Newport Optics move the two mirrors in a standard altitude-azimuth design. The azimuth stage uses a large RV240 model, which becomes the base of the whole tracker. A smaller URS75 rotator is used for elevation. Adjustable mirror mounts and the main aluminium-plate frame are custom made by a local CAD/CAM fabricator, as are the coaxial transformer parts.

The rotators use stepper motors in a micro-stepping mode. Identical microcontroller PCBs control each stage, as well as performing serial control and signal measurement functions. The elevation motor controller, GPS and a small power supply are located on the roof-mounted tracker in a weather-proof plastic box.

The remainder of the electronics consists of power supply modules, the azimuth motor controller, coaxial transformer amplifier and an (optional) Ethernet-to-serial convertor. All this resides in an enclosure next to the laptop in the lab below the tracker.

360 degree continuous azimuth rotation

Electrical power for the elevation electronics is transferred through the rotating azimuth axis using a custom coaxial transformer and electronics. The primary is driven with a pure 15kHz sinewave at about 50W. Bi-directional data to the elevation stage is sent via a short-range Bluetooth radio link from the lab below.

Figure 2. The coaxial transformer components.

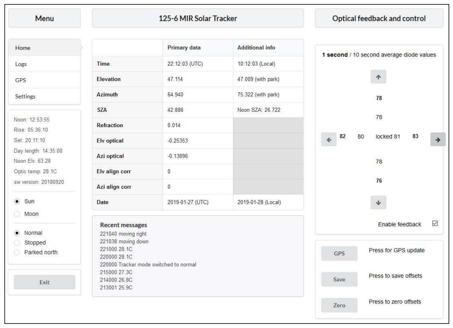

Figure 3. The main user interface is a webserver page

Application software now in Python

Prior to 2015, the controlling application was written in VB6 and ran on Windows. However the continual need for OS version upgrades, plus the regular interruptions caused by Windows and security updates, prompted a re-write in Python, to be run on Linux. This combination easily runs on retired hardware such as an ex-Windows laptop – a nice compact solution.

The Python application is written as a web server, using the ***Tornado framework***, making forward control of the hardware, by the client, a little bit easier. The web page can be accessed by any browser on the laptop itself. This doesn't need to be networked and the OS can remain unchanged, without any updates, until a new laptop is acquired.

If remote access is required, the laptop can be networked, with the tracker monitored and controlled from elsewhere. At NIWA, we run a second Ethernet card (and network) in the Windows PC used for the Bruker 125HR spectrometer. This same network is used to access the tracker via the PC's browser, in the same manner as we access the Bruker instrument webserver.

Optical Feedback

We rely on detecting the position of a large focused solar image, using 4 small IR silicon diodes, equally spaced around the circumference of the expected position. The advantage with this method, over a standard quadrant detector, is the high rate-of-change in illumination seen by the diode when the image moves off the edge of the small area of silicon. This, and the large solar image results in good detection precision. We find a diameter of 20mm is adequate to meet TCCON requirements.

A key algorithm in the application software translates any imbalance of the diodes' illumination into the correct offset to feed back to each mirror rotator. This continuously "nudges" the image into the centre where it belongs. We use a long integration period (about 10 seconds) for the signal and accumulate small changes in the offsets over time. In practice, we are mainly correcting for minor errors due to miss-alignment, poor levelling or temperature coefficients of the optical components. These are only significant over periods of minutes. The system is not especially sensitive to passing clouds, and when the threshold for cloud is reached, will resort to passive tracking (when we stop automated measurements anyway).

Potential disadvantages with this method include susceptibility to stray light, flattening of the solar disk at low elevation leading to errors, and the inherent fact the feedback is not directly coupled to the spectrometer (which is mounted on springs).

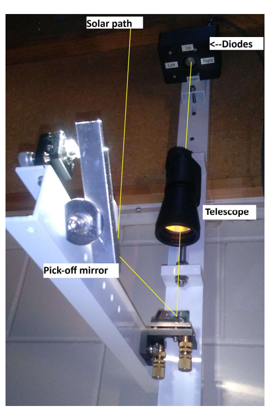

Figure 4. Active feedback optics.

Another useful feature – QA/QC

The tracker application generates daily log files. The file ***solar.txt***, lists the illumination of the 4 diodes plus the assessment of when it's "cloudy". We routinely use this file to QA the FTS measurements. If cloudy, the automation software does not start a measurement sequence. In post-processing QA/QC, we also delete any files that get flagged as cloudy during the duration of the measurement. Both of these actions are done automatically in Python applications running on the spectrometer's Windows PC.

Moon too

Stable dead-reckoning (non-feedback) tracking has made lunar (polar night) measurements of HNO_3 in Antarctica easier. The addition of a small camera could make optical feedback possible should we need to automate lunar measurements.

Accuracy

The major influences on dead-reckoning accuracy include the mounting and levelling of the tracker, and the care taken in the initial alignment of the tracker during construction.

When using optical feedback, the overall accuracy is limited by the design and stability of the feedback optics. At any time, total tracking accuracy and stability can be visually assessed by monitoring a small image of the sun, projected onto a distant wall with a miniscule mirror in the solar path.

Because the sun is a large rotating body, there is a degree of Doppler shift for wavelengths coming from the edges of the solar disk, as compared to the centre. Wavelength shift in the absorptions of gas in the solar atmosphere can be compared to those in the Earth's atmosphere. Any pointing away from centre of the sun can be detected (but only in the plane of solar rotation).

The plot below demonstrates the analysis of this SGShift, on a clear day, when both FTS were measuring. Two versions of optical feedback hardware are used. Instrument "Ir" shows room for some improvement on initial feedback "lock" speed at sun rise, perhaps tuning of software parameters would achieve this.

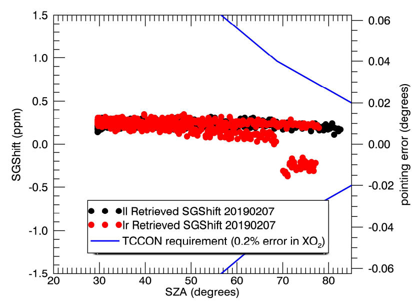

Figure 5. Pointing error inferred from the diagnosed SGShft parameter.

Summary

The current design works very well for us in Lauder and also for our more remote site in Antarctica. Typically, the tracker will run for over a year without needing a restart. The decision to move to Python and Linux has paid off, with no time-loss to IT issues or Windows restarts. Except for mirror cleaning, there's been little other maintenance required.

However, there's always room for further improvements. This may include:

- Enable on-the-fly changing of parameters - currently set in a config text file read on startup.
- Investigate using a small camera for optical feedback. This could image the FTS entrance aperture, or some other projected sample image. Although an increase in accuracy is not currently required, this camera could make solar limb measurements easier, allow for lunar optical feedback, and enable better assessment of the tracker's performance. This method also corrects for any minor changes in (sprung) spectrometer position in relation to the tracker tower.
- Speed-up the movement of the optics. At present the stepper algorithm is rather slow resulting in a movement cycle of about 1-2 seconds. This could improve initial lock at sunrise, for example.

Acknowledgements

We wish to thank colleagues at California Institute of Technology for initial funding and encouragement to start this project in 2005.

Colleagues at NIWA, past and present, have all contributed to the development of this design. We especially wish to thank Paul Johnston, Brian Connor and Alan Thomas.