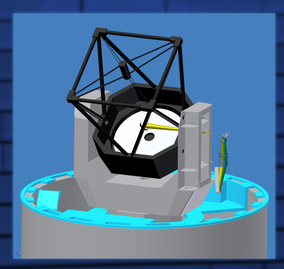
Tuning a 2.4 meter telescope... blindfolded

University of California Observatories

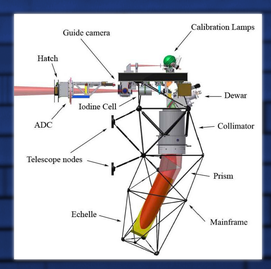
The Automated Planet Finder

The APF is the newest telescope sited at Lick Observatory, 32 kilometers east of San Jose near California's central coast. The APF is an altitude/azimuth telescope with a 2.4 meter mirror, enclosed in a co-rotating dome; the dome was designed and fabricated by Electro Optical Systems of Australia, and the telescope by EOS Technologies in Tucson, Arizona. The Levy spectrometer is installed at the left Nasmyth port, mounted directly to the telescope yoke; the instrument was designed and fabricated by University of California Observatories. The design objective for this telescope and spectrometer is high resolution Doppler spectroscopy. Instability in the servo control system of the telescope was a major roadblock for the commissioning of the facility; this paper describes some of the problems encountered, and the solutions deployed.

Open APF dome with the Shane telescope in the background



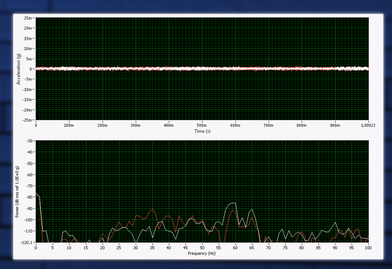
Model of the APF telescope showing the light path to the Levy spectrometer



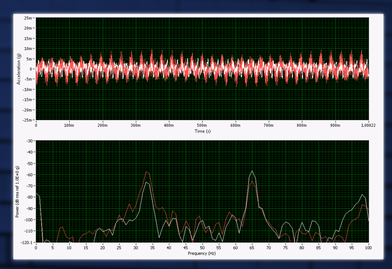
Schematic showing the major components of the Levy spectrometer

High resolution accelerometer feedback

No high-fidelity feedback was available via the vendor-provided control system. In order to make a quantitative assessment of the physical behavior of the telescope, a pair of Dytran 3191A1 accelerometers were installed on the telescope structure. Because these devices were not integrated with the existing control system, their feedback was available in all possible control modes. The accelerometers provided key data describing the nature of oscillations experienced by the telescope, allowing direct visual identification of uncontrolled oscillations, and the ability to measure the strength and characteristic frequency of any oscillation. The accelerometers enabled easy identification of mechanical resonances in the telescope, which could then be correlated with oscillations observed while the telescope was under computer control.



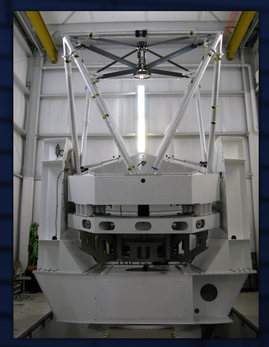
Example accelerometer output when tracking a stellar object; note the feature at 2 Hz, which is typical for nominal tracking performance



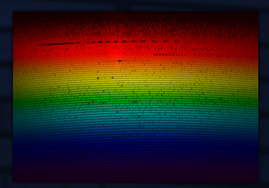
The data captured here shows a modest oscillation, with a characteristic frequency of 35 Hz; with a peak power above -60 dB, this would be audible in the dome

Shane 3-meter and APF 2.4 meter telescopes at Lick Observatory

APF at twilight, with the lights of San Jose in the distant background



APF telescope in Tucson before delivery to Mt. Hamilton



Spectral format of the Levy spectrometer; this is a solar spectrum with false color

Principal engineer Matt Radovan

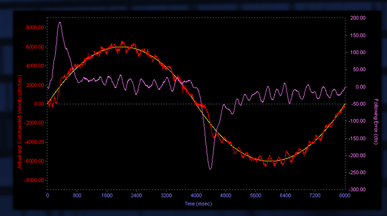
Project scientist Steve Vogt

Exiting the APF dome at twilight; don't forget to turn off the lights!

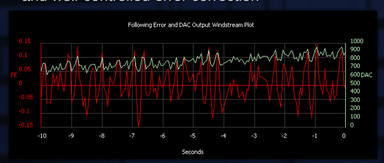
Delta Tau PMAC servo tuning

The tuning process first addressed components that could be isolated: zero point offsets, the current loop and gain in the servo amplifiers, and basic acceleration parameters; the process then moved to the traditional proportional, integral, and derivative servo control loop implemented on a Delta Tau Turbo PMAC motor controller. Adding an aggressive low-pass filter and maximizing the servo update rate were two key modifications that enabled the best performance for the APF. Using a combination of software from Delta Tau and EOST followed by on-sky testing, we implemented enough stiffness and precision in the control loop to meet or exceed the performance requirements of the telescope, with following errors tightly controlled at less than a tenth of an arc second at tracking speeds, and no uncontrolled oscillations at any speed.

Delta Tau step move test, showing rapid acceleration and well-controlled error correction



Delta Tau parabolic move test, showing minimal following error while accelerating at low speed

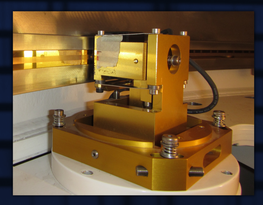


Following error and DAC output while tracking at a constant speed of 0.1 degrees per second

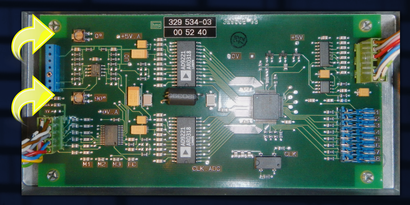
Following error and DAC output while tracking at a constant speed of 0.001 degrees per second

Alignment of Heidenhain linear encoders

The alignment of the Heidenhain linear encoder read head met the tolerances established by the manufacturer, but a significant nonlinearity in the quadrature output remained. This manifested itself as a perfectly repeatable oscillation with a characteristic frequency determined by the line spacing on the encoder tape and the velocity of the read head. Using test gear manufactured by Heidenhain and custom electronics to divide down the output from the encoder interpolators, UCO personnel were able to improve the alignment of the read heads from 2-8 degrees deviation down to 0.5-2 degrees; this reduced the amplitude of the oscillations, but did not eliminate them entirely. Only after adjusting undocumented potentiometers inside the interpolators themselves could the signal nonlinearity, and thus the persistent oscillations, be eliminated.

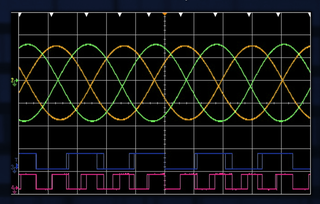


Adjustable mount for Heidenhain LIDA 10C linear encoder read head

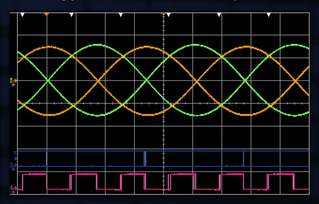


Interior of Heidenain EXE 660B interpolator, highlighting the location of the potentiometers

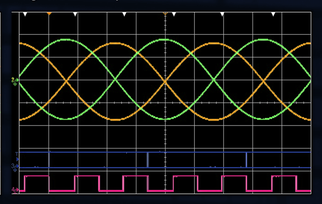
For the oscilloscope traces below, the quadrature output from the encoder read head are the sine waves in yellow and green; the square waves below are divided output from the interpolator. All the traces are triggered from two overlaid passes, 180 degrees out of phase.



Signal nonlinearity with 2-8 degrees of alignment error



Residual nonlinearity with 0.5-2 degrees of alignment error



Adjustments to the interpolator eliminate the residual nonlinearity

You don't need to wear a blindfold...

Get the documentation.

When contracting with a third party, you have no institutional memory to lean on when the time comes to extend, improve, or repair your facility. Mechanical designs, electrical schematics, software architecture overviews, thorough descriptions of key maintenance operations and procedures: they all play an essential role in streamlining the long-term sucess of your facility. Proper documentation should be an explicitly required deliverable in your overall contract and statement of work.

Get the source code.

Source code is effectively the ultimate documentation for any software delivered for your facility. Questions that go unanswered in the delivered documentation may have answers tucked away in the source code; in effect, the source code is the most direct and relevant example for how to properly interface with discrete hardware subsystems. Even if there is no intent to augment or otherwise modify the software, the source code retains enormous practical value as a detailed design document.

Analysis before empirical testing.

Complex systems are not necessarily amenable to direct empirical exploration of the solution space. In the case of servo tuning, it is easy to mistakenly convince oneself that a locally stable solution is globally stable. Independent analyses of the system, such as a swept-sine analysis, can expose chronic problems that could severely impact probing of the solution space. Determine in advance the aspects of your system that can be isolated, and explore those areas before moving on to more complex issues.

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