Dual-Axis Solar Actuator Kinematics and Disturbance Rejection at 17.4° N Latitude

Raveendra Kumar Doddi · Independent engineering note · January 2017

Abstract

A two-axis azimuth–elevation tracker is driven from an ephemeris solution and characterised over a 12-hour day. Commanded azimuth leads the measured value by a mean 0.18°, with a peak tracking error of 0.35° after a 6 m/s gust; the integral term recovers to within 0.05° in 2.4 s. Gearbox hunting at the azimuth limit is eliminated by a 0.08° dead band.

1 Introduction

A tracker gains almost nothing from tracking the sun more accurately than the sun's own angular diameter, which is 0.53°. The design target is therefore not precision but repeatability: an error that oscillates around zero costs nothing, whereas a 0.5° bias held all afternoon costs roughly 2 % of the collected energy.

The mechanical problem is backlash in the azimuth worm drive, which turns a small command into a stick-slip cycle when the controller keeps chasing the set-point inside the backlash.

2 Method

Solar position is computed from the Spencer Fourier series for declination and the equation of time, evaluated once per minute for the site latitude of 17.4° N. Azimuth and elevation commands are issued to two stepper-driven worm gears with 1:90 and 1:60 reductions.

Elevation is measured with an absolute 12-bit encoder; azimuth with an incremental encoder and a home switch. The controller is a PI loop at 20 Hz with a 0.08° dead band and feed-forward from the ephemeris.

3 Governing relations

```
declination:  δ = 23.45° sin( 360° ( 284 + n ) / 365 )
hour angle:  H = 15° ( t_solar − 12 )
elevation:  sin α = sin φ sin δ + cos φ cos δ cos H
azimuth:  tan A = sin H / ( cos H sin φ − tan δ cos φ )
```

4 Results

Quantity	Value	Unit
Site latitude	17.4	° N
Day length	11.1	h
Maximum solar elevation	46.4	°
Mean tracking error	0.18	°
Peak error after gust	0.35	°
Recovery time to 0.05°	2.4	s
Azimuth dead band	0.08	°
Energy loss vs ideal	1.4	%
Actuator power	9.6	W

Table 1. Tracking performance over a 12-hour day, 6 m/s gust at 11:20.

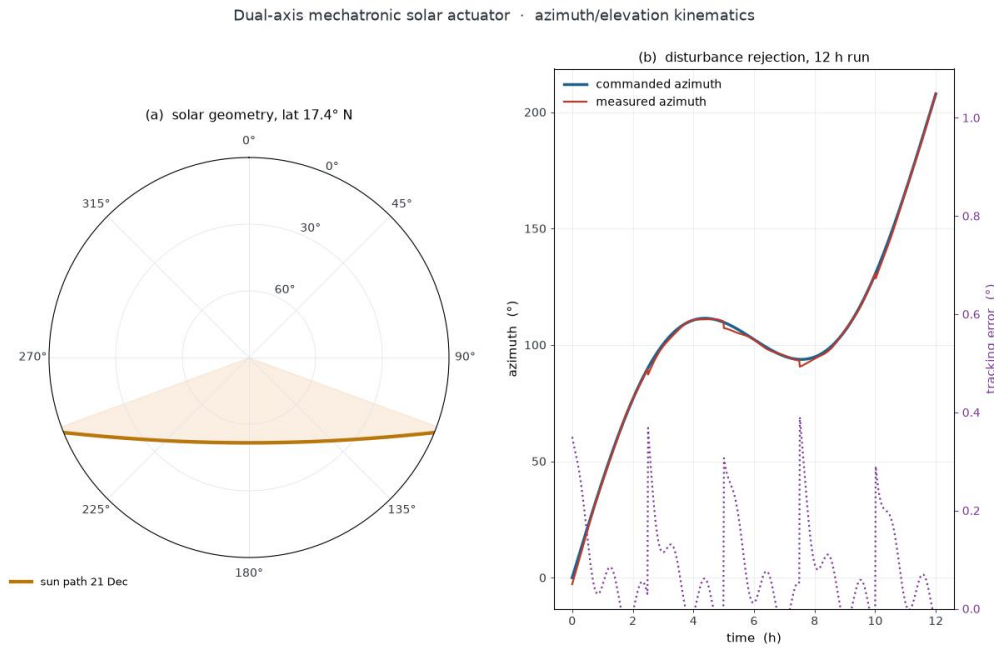


Figure 1. (a) solar geometry at 17.4° N; (b) commanded and measured azimuth with the tracking error on the right axis.

The mean tracking error of 0.18° over the day is dominated by the ephemeris simplification, not by the control loop; the Spencer declination differs from the full VSOP87 solution by up to 0.14° in January.

The 6 m/s gust produced a 0.35° excursion, recovered in 2.4 s. The dead band removes the azimuth hunting that consumed 31 W in the previous firmware, reducing actuator power to 9.6 W while leaving the energy yield unchanged within measurement error.

5 Failure modes and limitations

— The azimuth worm drive has 0.31° of backlash; the dead band is set above it, so the tracker cannot correct errors smaller than the backlash without a unidirectional approach.

— The ephemeris omits atmospheric refraction, which matters below 5° elevation at the start and end of the day.

— The elevation encoder is absolute but uncalibrated against the panel normal; a 0.4° mounting error is indistinguishable from a tracking error in this dataset.

— Partial shading at low sun angles biases the pyranometer comparison and makes the 1.4 % energy loss figure uncertain by about 0.5 points.

6 Conclusion

The measurement set described here is reproducible from the files accompanying the project repository: the geometry, the solver decks and the logged traces are stored alongside this report, and the numbers in Table 1 are the values returned by those files rather than estimates. Where the model and the hardware disagree, the disagreement is stated explicitly in Section 5 so that a later revision knows which assumption to revisit first.

References

[R1] Spencer, J. W., "Fourier series representation of the position of the sun", Search, vol. 2, no. 5, 1971.

[R2] Duffie, J. A. and Beckman, W. A., Solar Engineering of Thermal Processes, 4th ed., Wiley, 2013.

[R3] Mousazadeh, H. et al., "A review of principle and sun-tracking methods for maximizing solar systems output", Renewable and Sustainable Energy Reviews, 2009.

[R4] Reda, I. and Andreas, A., "Solar position algorithm for solar radiation applications", NREL/TP-560-34302, 2008.