Model based correction of heliostat tracking errors

Karel Malan
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Background + Motivation

• Heliostat field is 40-50% of plant cost
  → Focus cost reduction efforts here.

• Smart tracking- and error correction strategies may allow the use of low cost, low tolerance mechanisms + installation → SAVINGS

• Understanding control requirements is a vital step towards developing local CSP content
Objectives

• Develop high level control architecture for heliostat field (5MW_E SUNSPOT context).

• Validate control architecture with prototype system which is scalable and modular.

• Demonstrate open loop tracking and error correction method with “learning” capability to minimize errors over time.
Problem:
Each heliostat has a different local reference frame due to mechanical- and installation tolerances.

Calculate $\hat{h}$ to bisect $\hat{r}$ and $\hat{s}$.
Typical Sources of OL Heliostat Tracking Error

- Pedestal Tilt (non-vertical azimuth axis)
- Bias Offsets
  - Reference North ≠ REAL NORTH, Reference Horizon ≠ REAL HORIZON
- Heliostat Location offset
- Non-orthogonal axes
- Gravity Sag
- NB: All except location offset cause tracking errors which vary over days and seasons and cannot be corrected by single offset adjustments
Tilted Pedestal Daily Tracking Error (SE heliostat)

Date: 21/12/2012  Time: 07h00 - 18h00

Heliostat Location [m]
- Z: 1
- E: 30.8
- N: -19.2

Error Profile

Location Error [m]
- Z: 0
- E: 0
- N: 0

Pedestal Tilt [mrad]
- North-South: +1 / 0 / -1
- East-West: 0 / -1 / 0

Axes Bias [mrad]
- Azimuth 0
- Elevation 0
Pedestal Tilt “Corrected” with Angle Offset

**Date:** 21/12/2012  
**Time:** 07h00 - 18h00

![Graph showing vertical error vs horizontal error with data points and error profile for Heliostat Location and Pedestal Tilt.]

- **Heliostat Location [m]**
  - Z: 1
  - E: 30.8
  - N: -19.2

- **Error Profile**
  - **Location Error [m]**
    - Z: 0
    - E: 0
    - N: 0
  - **Pedestal Tilt [mrad]**
    - North-South: 1
    - East-West: 0
  - **Axes Bias [mrad]**
    - Azimuth: 0
    - Elevation: 1
Inter-seasonal Variation of Tracking Error

- Dates: See below
- Time: 07h00 - 18h00

<table>
<thead>
<tr>
<th>Dates</th>
<th>Vertical error [mrad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z: 1</td>
<td>7</td>
</tr>
<tr>
<td>E: 30.8</td>
<td>3.5</td>
</tr>
<tr>
<td>N: -19.2</td>
<td>0</td>
</tr>
</tbody>
</table>

Error Profile

- Location Error [m]
  - Z: 0
  - E: 0
  - N: 0

- Pedestal Tilt [mrad]
  - North-South: 1.87
  - East-West: 2.35

- Axes Bias [mrad]
  - Azimuth: 4
  - Elevation: 3

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System Overview

- CENTRAL FIELD CONTROLLER
  - Scheduler
  - Error Model Parameter Estimation
  - I/O
  - Database
  - Image Processing

- DISTRIBUTED PROCESSING + COMMS NETWORK

- HELIOSTAT LOCAL CONTROLLER i
  - Open-Loop Tracking + Error Correction

- SUN

- RECEIVER

- CALIBRATION TARGET

- CAMERA

- HELIOSTAT i of 10 000

AZIM / ELEV MOTOR CONTROL
Distributed Control (3 Processing Levels)

- All real-time tasks handled by Cluster- and Local Controllers

**Upper Level:** Central
- Central Field Controller
  - Error Model Parameter Estimation
  - Database
  - Scheduler
  - Image Processing
  - I/O

**Mid Level:** Cluster
- Cluster Controller
  - Comms Multiplexing
  - Solar Algorithm

**Lower Level:** Local
- Heliostat Local Controller
  - Step Counts, Status
  - Solar Vector (every sec)
  - Serial BUS (RS485)
  - Normal Vector Calc
  - Error Correction
  - Motor Control

32 Heliostat CLUSTER (semi autonomous)
Scalability (one possible wired layout)

48 x 32 = 1536 Heliostat SECTOR
Results: Curve Fitting
Measured vs Modeled Error Curves 02/09/2012

- Measured uncorrected (BLUE)
- Model Fit (GREEN)
- Modeled Residual (MAGENTA)
- Measured Residual (RED)

lens flare period: 14:00 - 16:00
Software Calibrated Heliostat Open-Loop Tracking

Period: 13/09/2012  09h15 – 18h00 @ 24min/sec.
Slant Range ≈ 37m.  $\hat{n}_H$  $E_{\text{RMS}} \approx 0.9 \text{ mrad}$

Note changing spot intensity and flaring (00:13→)
3 Days’ OL Tracking

X and Y vs time. 06-08 Aug 2012: 09h15 - 18h00

Strong correspondence suggests residual determinism.

→ Further characterization may be possible which could allow improved OL tracking performance.
Sasol Helio40 under construction

20 x 2m² single facet heliostats.

Mixture of: Fixed Horizontal (LA driven)
Azimuth-Elevation (Slew + LA driven).
‘Helio-18’ Start-up and Stow
‘Helio-40’ prototype heliostat (FH)
Thank you.

Questions?