An International Heliostat Consortium (HelioCon): Progress Highlight in 2023

Guangdong Zhu, NREL
On behalf of HelioCon team

October 11th, 2023 • SolarPACES 2023 • Sydney, AU
HelioCon: Team

- Leadership team:
  - NREL researchers and administrative support
    - Lead: Guangdong Zhu, Ph. D.
  - Sandia researchers
    - Lead: by Margaret Gordon, Ph.D.

- Non-voting members:
  - ASTRI: Australian Solar Thermal Research Institute

- Board of Advisors
  - Utility, developers, plant owners, component suppliers, EPCs, Academia, standards and international advisors

- Members
  - RFP awarded project performers
  - Other Consortium funded project performers and cost-share providers.

- Non-consortium stake-holders
  - Subject-matter experts; U.S. and international institutions.
A Glance of Sub-Team at NREL

Chad Augustine  Raven Barnes  Miriam Coron  Jack deBloois  Mackenzie Dennis  Rebekah Durand  Ulrike Egerer  Tucker Farrell
Cindy Gerk       Mike Grabel   Patrick Hayes  Kyle Heinzman   Maggie Kautz   Mojo Keshiro  Devon Kesseli  Louis King
Parthiv Kurup    Dylan Mayes   Mark Mehos    Rebecca Mitchell Matt Muller    Jessica Roe  Gabriel Shuster  Katelyn Spadavecchia
Brooke Stanislawski  Linh Truong  Daniel Tsvankin  Evan Westphal  Shashank Yellapantula  Guangdong Zhu  Alex Zolan
A Glance of Sub-Team at Sandia

Jeremy Sment
Margaret Gordon
Randy Brost
Kenneth Armijo
Braden Smith
Rebecca Schaller

conceptual design • components • integration • mass production • heliostat field
A Glance of Sub-Team at ASTRI

Mike Collins - CSIRO
Joseph Coventry - ANU
Matthew Emes - Adelaide
Michael Cholette - QUT
Dominic Zaal - ASTRI

Giovanni Picotti - QUT
John Pye - ANU
Michael Rae - CSIRO
Maziar Arjomandi - Adelaide
Ye Wang - ANU
A Glance of Sub-Team from RFP Projects

Kyle Kattke – SD SunRing
Rick Sommers – SD Wireless
Roger Angel - UAz
Hank Price – SD SunRing
Eric Belski - Sarcos
Hameed Metghalchi - Northeastern
Eirini Eleni Tsiropoulou - UNM
Michel Izygon - Tietronix
Outline

- HelioCon management
- Metrology & standards
- Components & controls
- Field deployment
- Techno-economic analysis
- Resources, Training and Education
- RFP projects
- Not HelioCon, but related
Outline

- HelioCon management
  - HelioCon website
  - HelioCon seminars
- Metrology & standards
- Components & controls
- Field deployment
- Techno-economic analysis
- Resources, Training and Education
- RFP projects
- Not HelioCon, but related
Project: HelioCon Website

• Objectives
  • Create a place to promote the heliostat technology and its application
  • Create a place to share the resources with the public

• Approaches
  • An independent website with prompt updates

• Status
  • Fully developed website framework
  • Timely update the contents
  • increasing visits

• Leads: Cindy Gerk, Patrick Hayes, NREL
Project: HelioCon Seminars

**Objectives**
- Share the knowledge and insights of top-notch experts to the whole communities

**Approaches**
- Host, record and share seminars with the public

**Status**
- 16 expert seminars
- 2 training seminars

**Lead:** Rebecca Mitchell, NREL
Outline

- HelioCon management
- **Metrology & standards**
  - OpenCSP
  - SOFAST
  - NIO technology
  - ReTNA technology
  - NREL third-party platform development
  - Slope error data reporting
  - Slope error conversation from photogrammetry
  - Soiling measurement
  - Heliostat shape estimation
  - Mirror soiling
- Components & controls
- Field deployment
- Techno-economic analysis
- Resources, Training and Education
- RFP projects
- Not HelioCon, but related
Project: OpenCSP

**Objectives:**
- Establish a community library of CSP foundation classes, algorithms and applications

**Approach:**
- Develop the coding standards
- Establish foundation classes, core algorithms and automated tests
- Promote community collaboration to develop and, when ready, release new applications to the whole CSP community

**Status:**
- Established foundation for OpenCSP diagnostics
- In next year, to release first version of OpenCSP and ground truth for wide use

**Lead:** Randy Brost, Sandia
**Project: SOFAST Upgrades**

- **Objectives**
  - High-resolution, fast, slope measurement for both facets and full heliostats.
  - Suitable for:
    - Prototype development
    - Manufacturing process development
    - High-volume factory production
  - Multiple improvements in code quality, extensibility, flexibility, ease of use, application to key new problems.

- **Approach**
  - Deflectometry.
  - High-quality code, simplify calibration.
  - Check against ground truth.

- **Status**
  - Version 1 in commercial use.
  - Version 2 nearing completion.

- **Lead:** Randy Brost, Sandia
Project: NIO Technology

• **Objectives**
  - In-situ technology suitable for utility-scale heliostat fields
  - Measure slope error, canting error and tracking error

• **Approach**
  - Drone-driven camera
  - Reflectometry
  - Automated image-processing through computer vision and machine learning

• **Status**
  - Entering into demonstration stage
    - NSTFF (done)
    - Crescent Dunes (done)
    - Cerror Dominador (planned)

• **Leads:** Tucker Farrell, Rebecca Mitchell, NREL
Project: ReTNA Technology

• Objectives
  • Laboratory technology suitable for single heliostat prototype
  • Portable, efficient and automatic
  • Measure slope error, canting error
    • Varying orientation
    • Varying load

• Approach
  • Deflectometry & photogrammetry
  • Automated image-processing through computer vision and machine learning

• Status
  • Completed concept-proof stage
  • Building a prototype at NREL

• Lead: Devon Kesseli, NREL
Project: Third-Party Evaluation Platform at NREL’s Flatirons Campus

• Objectives
  • Make available third-party heliostat performance assessment capabilities to serve CSP industry.
    o evaluation of heliostat designs under indoor and outdoor conditions
    o validation of newly developed metrology technologies by others

• Approach
  • Develop/acquire, install and calibrate most-advanced metrology technologies within HelioCon
  • Demonstrate the test capability with a case study
  • Call for test services on commercial heliostat designs

• Status
  • Developing new techniques

• Lead: Rebecca Mitchell
Project: Slope Error Data Processing & Reporting

Objectives

• Standardise methods for slope error data processing and reporting

Approach

• Develop software tools for data processing and reporting
• Test against shared data sets
• Release library as open source (pending approval)

Status

• Software tools developed and tested on CSIRO point cloud surface data. Initial results shared with Helioco

Leads: Mike Collins, Calum Acutt, CSIRO
Project: Slope errors from photogrammetry

Objective

- To implement, as open source code, a method for converting photogrammetry point-cloud data to equivalent slope error values.

Approach

- Acquire point-clouds from images using projected or adhered dots and process using commercial “VMS” photogrammetry tool.
- Implement a new Python script based on previous IDL/Matlab ANU code: Delauney triangulation, axis alignment, paraboloid fitting, residual fitting to Rayleigh and Normal distributions.

Status

- Initial code developed and shared at https://github.com/anustg/Solar_concentrator_optics.git
- Next: close the loop also by cross-checking flux mapping and ray tracing.

Leads: Johannes Pottas, Ye Wang, John Pye, Joe Coventry, ANU
**Project: Soiling estimation from DSLR images**

**Objectives:**
- Develop a cost-effective way to significantly improve the spatial and temporal resolution of soiling loss estimation.

**Approach:**
- Use an original color-space processing method to estimate mirror reflectance and soiling loss.
- Gather camera images and reflectometer-based soiling measurements from multiple heliostat technologies and sites to test the method.

**Status:**
- Controlled conditions result in <1% error in reflectance estimation.
- Currently evaluating the impact of the image acquisition parameters on the accuracy of the method.

**Leads:** Charles-Alexis Asselineau & Joe Coventry
**Objective**

- To use images from a beam characterisation system (BCS) for in-situ heliostat shape and slope error measurements and spillage quantification

**Approach**

- Acquire beam images of a heliostat at different times of a day using BCS
- Matching the flux distributions from ray-tracing and image data by optimising the shape of the heliostat that is governed by coefficients of a quadric equation

**Status**

- Streamlined software process has been developed and applied to flux image data previously acquired at Vast Solar (Australia)
- New image data were acquired at IMDEA (Madrid, Spain) and are being processed to validate against deflectometry data

**Leads:** Ye Wang, Charles-Alexis Asselineau, Joe Coventry and John Pye

**Equation:**

\[ z = ax^2 + by^2 + cxy \]

**Diagram:**

1. **Image acquisition using BCS (with stitching if necessary)**
2. **Heliostat shape estimation**
   \[
   \begin{bmatrix}
   x^2 & y^2 & x^2 & y^2 & xy & x & y & 1 \\
   x & y & x & y & x^2 & y^2 & xy & 1 \\
   \end{bmatrix}
   \]
   - Image data
   - ray tracing flux maps
   - Obtain the optimal $a$, $b$, $c$ that minimise the difference in flux distributions
3. **Optical performance of the entire field**
Project: Mirror Soiling

**Technical**
- Complete a benchmarking study with different soiling models (underway now)
- Dust sampler installation at NSTTF and a long-term soiling campaign
- First camera-based soiling measurements at
- Workshop to get input and contributions for soiling database (via follow-up with contacts in SolarPACES Task III and other previous outreach efforts).
- Soiling campaigns in Port Augusta, South Australia (travel funding permitting)
- Activities to better understand soiling processes to support site selection:
  - Experiments on effects of moisture on adhesion and deposition
  - Refinement of reflectance model via Mie Scattering
  - Experiments at the ABLRF to understand key atmospheric boundary layer conditions that affect soil deposition
- Begin work on including cleaning considerations in design of plant (receiver capacity, solar field size/layout)

**Engagement with Industry and Researchers**
- Continue engagement with Vast Solar on soiling
- Visit to PSA by QUT PhD student Cody Anderson
- Participation (and NREL leadership within) SolarPACES Task III
- Seek out more companies designing cleaning systems

**Publications and reports**
- Submit a paper on cleaning optimization work with Ivanpah (will require partner permission)
- Submit paper on moisture effects
- Submit a paper on the soiling predictive model benchmarking

**Leads:** Michael Cholette, QUT
Outline

• HelioCon management
• Metrology & standards
• **Components & controls**
  • Composite heliostat design evaluation
  • Solar field closed-loop control testbed
  • Heliostat design qualification standard
• Field deployment
• Techno-economic analysis
• Resources, Training and Education
• RFP projects
• Not HelioCon, but related
Project: Composite Heliostat Design Evaluation

• Objectives
  • Evaluate potential of composite materials for heliostat mirror facets and structure for meeting the DOE cost target goal: $50/m2

• Approach
  • Perform initial design optimization for reducing heliostat cost
  • Carry out cost comparison between composites and the state of art materials/design

• Status
  • Initial results discourage use of unidirectional composites; structural facets (sandwiched composites) or alternatively-designed heliostats optimized for composite beams suggested

• Leads: Matt Muller, NREL

Purlin results, 9.90mrad peak local slope deviation

Cost
  - Steel
  - Glass
  - Basalt
  - Carbon

Weight
  - Steel
  - Glass
  - Basalt
  - Carbon
Project: Heliostat field closed-loop control system testbed development

• Objectives
  • Develop a closed-loop control system testbed to assess the durability of heliostat components and closed loop controls, and ensure their qualities under realistic operational conditions in future commercial projects

• Approach
  • Upgrade Sandia’s NSTTF heliostat field with respect to both software and hardware
  • Develop new control software able to accommodate real-time heliostat aiming and closed loop feedback algorithm.
  • Develop new communication infrastructure for wireless communication test

• Status
  • The testbed is in the design stage
  • Software architectures utilized to determine optimal pointing of each heliostat, accounting for unique metrology considerations

• Lead: Ken Armijo, Sandia
Objectives
- Develop a standard on: Technical requirements and design qualification of heliostats for solar power tower plants

Approach
- NREL is co-leading the development with Cosin Solar from China

Status
- Working group has been formed
- New standard proposal was just submitted to IEC for the NP approval.

Lead: Daniel Tsvankin, NREL
Outline

- HelioCon management
- Metrology & standards
- Components & controls
- Field deployment
  - Third-party high-fidelity solar field performance prediction model
  - Analysis of Heliostat O&M at Ivanpah
  - Ecological impacts
  - Wind load characterization
- Techno-economic analysis
- Resources, Training and Education
- RFP projects
- Not HelioCon, but related
Project: High-Fidelity Performance Model

• Objectives
  • High-fidelity performance model to fill the gap between project developers and investors

• Approach
  • Define required site-specific data
  • Define required heliostat and heliostat field data
  • Define performance output metrics with associated uncertainties
  • Integrate a suite of modeling tools with necessary improvement

• Status
  • Identifying key sources of uncertainty in performance models

• Lead: Alex Zolan, NREL
Project: Analysis of Heliostat O&M at Ivanpah

- **Objectives**
  - Obtain field measurements at an operating facility to observe soiling conditions
  - Compare performance of measurement devices and analyze mirror cleaning activities

- **Approach**
  - Obtained >500 measurements across ~120 heliostats in solar field of Unit 1
  - Developed separate models of soiling and cleaning optimization using (a) field-collected data, and (b) historical measurements shared by Ivanpah

- **Status**
  - Results confirmed that Ivanpah's cleaning frequency is appropriate, but it may be worth considering adjusting the cleaning schedule seasonally
  - Final report including analysis completed
  - Report on lessons learned for planning field measurement campaigns under development

- **Lead**: Alex Zolan, NREL
Project: Analysis of Ecological Impacts

• Objectives:
  • Quantify the effects of heliostats on habitats and survivability of tortoises
  • Determine a methodology for field deployment and O&M that conforms to US Fish and Wildlife goals and regulations with coexistence of protected species and heliostats
  • Demonstrate automated detection techniques using UAVs as part of methodology

• Approach:
  • Measure temperature, moisture, and vegetation in quadrats at an existing plant, approved future plant sites to determine the impacts of heliostat shading on habitat
  • Work with Ivanpah Biologists for historic observations on the 2013 plant deployment and leverage existing data on the health and tracking of desert tortoises near Ivanpah
  • Consulting with US Fish and Wildlife Service to refine study approach, advise permitting requirements, and co-develop a methodology to satisfy the ESA and industry viability.
  • Conducts tortoise surveys with UAVs and will help to inform the best practices approach to minimize the cost of identifying tortoises

• Status:
  • Project scoping study initiated with biologist collaboration
  • Identified contacts at US Fish and Wildlife Service and Ivanpah Solar Energy Project

• Lead: Jeremy Sment, NREL
Project: Heliostat Wind Load Field Measurements

- **Objectives**
  - Develop detailed measurement procedure to reconcile single heliostat load field measurements with wind tunnel experiments
  - Investigate loads in low- and high-density arrays of heliostats for wind load prediction in a heliostat field at different elevation angles

- **Approach**
  - Field measurements at UoA Atmospheric Boundary Layer Facility (ABLRF) Roseworthy campus to verify single heliostat loads with wind tunnel data
  - Heliostat field array load and flow measurements in different rows of linear staggered field array

- **Status**
  - Single heliostat load field measurements consistent with wind tunnel data for prevailing wind direction, other wind directions to be analyzed
  - Increasing load reduction in downstream rows of heliostat array for increasing elevation angle and increasing field density

- **Lead**: Matthew Emes, U. Adelaide
Outline

- HelioCon management
- Metrology & standards
- Components & controls
- Field deployment
- Techno-economic analysis
  - Process heat system of heliostats
- Resources, Training and Education
- RFP projects
- Not HelioCon, but related
Project: Heliostat Field Optimization for Power Tower Solar Industrial Process Heat Applications

- **Objectives**
  - Develop heliostat field, tower, and receiver model for industrial process heat (IPH) applications.
  - Determine practical and commercial operating limits for IPH applications (temperature, project size, impact of receiver media, etc.)
  - Develop field layout “best practices” for IPH applications

- **Approach**
  - Develop cost correlations for tower and receiver for IPH
  - Optimize base case field layouts based on cost correlations

- **Status**
  - Improving models required for TEA analysis
  - Carrying out initial sensitivity analysis

- **Lead:** Chad Augustine, NREL
Outline

• HelioCon management
• Metrology & standards
• Components & controls
• Field deployment
• Techno-economic analysis
• **Resources, Training and Education**
  • HelioCon database
• RFP projects
• Not HelioCon, but related
**Project: HelioCon Database**

**Objectives**
- Establish a publicly accessible web-based resource database containing fundamental and expert knowledge

**Approach**
- HelioCon will gather available resources and knowledge into web database:
  - Industry knowledge: stakeholder contacts, O&M/manufacturing/design practices
  - Resource library: references, trainings, software tools
  - Resources/guidance for promoting diversity, equity, and inclusion

**Status**
- Has completed 1) reference library; 2) Education and training resources; 3) Lists of heliostat component suppliers and developers, metrology tools, and software tools; 4) Existing power tower plant database

**Lead**: Rebecca Mitchell, NREL
Outline

• HelioCon management
• Metrology & standards
• Components & controls
• Field deployment
• Techno-economic analysis
• Resources, Training and Education

• RFP projects
  • 7 issued in Round 1
• Not HelioCon, but related
Round 1 RFP Awardees Announced in June 2023: Total $3.5M, 7 Awardees

- Solar Dynamics - SunRing: Advanced Manufacturing and Field Deployment
- UNM HELIOCOMM: A Resilient Wireless Heliostats Communication System
- Northeastern U. - An Educational Program on Concentrating Solar Power and Heliostats for Power Generation and Industrial Processes
- Solar Dynamics - Demonstration of a Heliostat Solar Field Wireless Control System
- U. of AZ - Actively Focused Lightweight Heliostats
- Tietronix - Digital Twin and Industry 4.0 in Support of Heliostat Technology Advancement
- Sarcos - Robotic-Assisted Facet Installation (RA-FI)
Outline

• HelioCon management
• Metrology & standards
• Components & controls
• Field deployment
• Techno-economic analysis
• Resources, Training and Education
• RFP projects

• Not HelioCon, but related
  • Ray-trace round robin test
  • Laboratory slope error metrology round robin
  • Windload test campaign
  • Avian hazard mitigation
Project: Raytrace Model Round Robin Test

- **Objectives**
  - Examine/improve (if necessary) accuracy of raytrace models available in the market

- **Approach**
  - Perform case studies to validate three raytrace models through round robin test
  - Validate other soltrace models per request

- **Status**
  - Near completion of round robin test of three raytrace models

- **Leads**: Rebecca Mitchell, Ye Wang (ANU), Michel Izygon (TieTronix), John Pye (ANU)
Objectives

- Examine/improve (if necessary) accuracy of laboratory slope error metrology available in the market

Approach

- Perform round robin test within 5 institutes: ENEA, DLR, Fraunhofer, Sandia, NREL
- Collaborate with international community with support from EU program

Status

- Collecting and measuring mirror facets shipped from Europe partners

Lead: Marco Montecchi, ENEA

Project: Laboratory Slope Error Metrology Round Robin Test
Project: Wind load Characterization

• Objectives
  • Develop detailed measurement procedure to characterize the prevailing wind conditions and resulting operational loads
  • Develop and validate a computationally efficient, high-fidelity modeling tool capable of predicting wind-loading in deep-array installations.

• Approach
  • Carry out measurement campaign at parabolic trough power plant – Nevada Solar One
  • Carry out measurement campaign at Crescent Dunes power tower plant
  • Validate CFD model with experimental data

• Status
  • Near to completion of parabolic trough collector field measurement and model validation
  • To plan the measurement campaign at Crescent Dunes power plant

• Lead: Shashank Yellapantula, NREL
Project: Surveillance and Mitigation of Avian Flux Hazards

- **Objectives**
  - Protect avian wildlife at operating CSP tower facilities.
  - Inform site design and operation decisions of future CSP tower facilities that optimize for minimum disruption to avian wildlife.

- **Approach**
  - Reconfigure the Temporal Frequency Analysis (TFA),
  - Create the Avian Detection and Collection System (ADACS),
  - Develop and design a new industry-focused Full-Field Irradiance Analysis Model (FFIAM) to summarize the expected irradiance of a heliostat field when in standby.

- **Status**
  - Completed an initial optical design and prototype of ADACS
  - Began on work on the FFIAM tool.
  - Began on work on the avian mortality review of the Ivanpah CSP.

- **Lead**: Dan Small, Sandia
Project: Commercialization of Non-Intrusive Optical (NIO) Technology

• Objectives
  • Create a commercial NIO package with a user-interface and documentation and training, and capability services to meet stakeholder needs.
  • Perform a commercial demonstration of the NIO tool by performing data collection activities and providing optical error data deliverables to a plant partner.
  • Produce a business strategy to market and launch a beta version of the commercial tool package at the conclusion of the project.

• Approach
  • Design NIO services and capabilities based on industry stakeholder feedback.
  • Test NIO commercial tool capabilities and operation procedures with a large-scale data collection campaign at a commercial plant.

• Status
  • Streamlining and validating NIO algorithm performance.
  • Coordinating with candidate commercial plants for data collection activities.

• Lead: Rebecca Mitchell, NREL
Project: Commercialization of the Reflected Target Non-intrusive Assessment (ReTNA)

- **Objectives**
  - Create a commercial NIO package with a user-interface and documentation and training, and capability services to meet stakeholder needs.
  - Perform a commercial demonstration of the NIO tool by performing data collection activities and providing optical error data deliverables to a plant partner.
  - Produce a business strategy to market and launch a beta version of the commercial tool package at the conclusion of the project.

- **Approach**
  - Design NIO services and capabilities based on industry stakeholder feedback
  - Test NIO commercial tool capabilities and operation procedures with a large-scale data collection campaign at a commercial plant.

- **Status**
  - Streamlining and validating NIO algorithm performance
  - Coordinating with candidate commercial plants for data collection activities

- **Lead:** Devon Kesseli, NREL
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