U.S. Department of Energy
HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

Heliostat Consortium Seminar Series

Brought to you by the Resource, Training, and Education (RTE) topic area

Abstract:

The Heliostat Consortium (HelioCon) is a 5-year research effort led by the National Renewable Energy Laboratory (NREL) partnering with Sandia National Laboratories (SNL), the Australian Solar Thermal Research Institute (ASTRI), and DOE's Solar Energy Technologies Office, to develop and manage a national laboratory-led U.S. consortium to support research, development, validation, commercialization, and deployment of low-cost heliostats for concentrating solar power (CSP) and solar thermal (CST) applications. Project team members at NREL and SNL have taken on eleven interns over the second year of the project to work on a wide range of projects within HelioCon. Each intern will provide a description of their project and highlight key outcomes and findings.

Interns Presenting:

NREL

Jack deBloois
Miriam Caron
Mojo Keshiro
Michael Grabel
Kyle Sperber
Daniel Tsvankin

SNL

Benjamin Bean
Zachary Bernius
Haden Harper
Madeline Hwang
Tristan Larkin

Title: Intern Projects in Heliostat Technologies at NREL, SNL

Host: Dr. Rebecca Mitchell

When: Aug 16th 1:30-3 PM MDT

Zoom:
https://nrel.zoomgov.com/j/1603871116

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Jack deBloois
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National Renewable Energy Laboratory (NREL)

Mentor: Tucker Farrell

Project Title: Beam Characterization System Development and Integration at Outdoor Lab Location

Abstract:

Beam Characterization System (BCS) analysis is used to determine tracking and canting error on heliostats. This requires a target for the heliostat to aim at and a stationary camera to record the light beams. My project goals are as follows: design and analyze a low-cost target structure with high surface flatness and survivability in high wind conditions, acquire and test the integration of a machine vision camera, and work with multiple departments to fabricate and deploy the system at a test site. After multiple reviews of the survivability and fabrication methods the target structure is now ready for fabrication and deployment. The camera is being tested with a custom python script that will analyze the beam reflected on the target.

Bio:

Jack is a recent graduate with a bachelor's degree in mechanical engineering. His focus is on mechanical design and system integration. At NREL he has contributed mechanical designs and analysis alongside a budget analysis for the BCS project for the thermal energy systems group. He is passionate about Formula 1 and building custom PCs. He enjoys skiing, video games, and tennis during his free time.

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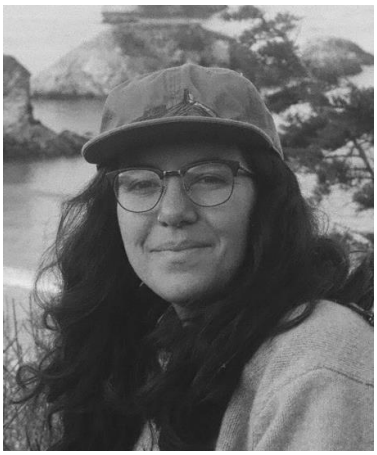

Miriam Caron
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National Renewable Energy Laboratory (NREL)

Mentor: Dr. Rebecca Mitchell

Project Title: Increasing User Ease and Efficiency of the Non-Intrusive Optical Method

Abstracts:

Concentrating Solar Power (CSP) tower plants contain a field of parabolically shaped mirrors, called heliostats, that reflect sun rays into a receiver mounted on a central tower. The heliostats are programmed to move with the sun throughout the day, like sunflowers. However, small optical errors in the heliostats cause large power production losses to the plant. To address this, I have been contributing to a software repository of a drone-based metrology tool that detects optical errors in the heliostats quickly and without intruding on the performance of the CSP plant called the Non-Intrusive Optical (NIO) method. The NIO method software intakes images of heliostats in a field taken by a drone and outputs the heliostats' optical error. I have been working to make the NIO method code less computationally expensive and more user friendly so that it can be commercialized sooner. Developing solar field measurement methods is key to preventing costly installation or operation mistakes and improve the reliability of the technology area. Cost and reliability are the main barriers to overcome for CSP to become economically viable and to grow into a larger role in the renewable energy economy.

Bio:

Miriam is a recent graduate of Pitzer College in Claremont, CA where she majored in Mathematics and Physics. She first joined NREL as a participant in the Department of Energy's Science Undergraduate Laboratory Internship (SULI) program in January and has stayed on as a post-undergraduate intern. Prior to working at NREL she mainly researched theoretical algorithms to further quantum computation. In her seven months at NREL she has been working on the Non-Intrusive Optical (NIO) method's code for surveying heliostats in a CSP tower field. Her work at NREL has exposed her to the wide variety of renewable energy technologies and ensured her commitment to focusing her career on decarbonization. Miriam will soon start applying to masters' programs where she would like to focus on climate solutions. In her free time Miriam enjoys climbing mountains, reading, watching movies, going to concerts and rock climbing.

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Mojolaoluwa Keshiro
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National Renewable Energy Laboratory (NREL)

Mentor: Devon Kesseli

Project Title: Reflected Target Non-Intrusive Assessment (ReTNA) Improvement

Abstract:

Fast, low-cost characterization of heliostat and parabolic trough optics is essential for well-performing concentrated solar fields. Following the successful development and validation of a prototype lab scale heliostat optical error characterization tool, we went forward to improve the methodology, data collection procedures, and equipment. Reflected Target Non-Intrusive Assessment (ReTNA) is a system for quickly measuring heliostat surface shape and facet canting by capturing images of reflected, printed targets. Continued development of ReTNA focused on automation and the creation of a new adaptable setup that can be used to measure heliostat optics at a variety of pointing angles, and on the assembly line. Automotive data capture was achieved by use of a new camera system; high precision photogrammetry was achieved by use of fiducial markers. The new camera system enables auto movement of the camera, auto picture capture and auto picture transfer wirelessly. Fiducial markers like ArUco and ChArUco boards were implemented in the methodology as the printed targets for easy, fast, and precise detection and pose estimation.

Bio:

Mojo is a post graduate intern who got his master's degree in mechanical engineering at the University of Colorado, Denver. He has a career interest and experience in thermal engineering. He has had experience in traditional thermal power plants, piping design and now renewable energy technology development. His work at NREL has been primarily around coding development and improvement, research, data analysis and experiments. He loves to work on renewable energy projects, challenging himself across the different technologies. He had his undergraduate degree in Mechanical Engineering also. He has experience with and skills for project management and marketing. A large amount of his project management experience is from volunteering on and creating projects for social change he is passionate about.

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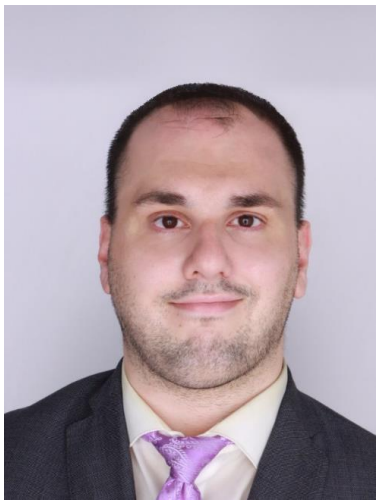

Michael Grabel
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National Renewable Energy Laboratory (NREL)

Mentor: Dr. Rebecca Mitchell

Project I Title: Heliostat Recourse Database

Project II Title: Camera Position Estimation Sensitivity Analysis for Heliostats

Abstract:

Project I
A major goal of the HelioCon project is to provide more public accessibility of heliostat industry and concentrating solar power (CSP) knowledge through a centralized web-based database. I gathered a list of suppliers for all the heliostat components, available software, and metrology tools used for CSP plants. Also adding onto the educational information developed by Mackenzie, a prior intern. Data was also collected on all 29 power tower CSP plants in the world. Python code was also developed that generates a summary document for each plant based on this data. All of this collected and compiled information is displayed on the HelioCon website.

Project II
NREL's Non-Intrusive Optical (NIO) tool measures mirror surface slope, canting, and tracking error using photogrammetry. The Uncrewed Aircraft System (UAS) collects images over a field of heliostats and NIO processes the images to calculate the error. The calculation of this UAS camera position is an important step in the algorithm. It is needed to rescale the arial image to be of just the heliostat using the photogrammetry equations. The accuracy of the camera position calculation depends on how accurately the pixel locations on the image of a heliostat and their corresponding 3D world location points can be measured. If we are trying to determine the camera position of a UAS drone flying over a heliostat field as in the NIO methodology, we want to know which points and how many points provide the most accurate camera position so we can determine the location of the drone for NIO. The goal of this project is to determine which subset of control points that provides the least amount of error in camera position estimation.

Bio:

Mike is a PhD student in biostatistics with a background in mathematics. The research in maths he enjoys is in mathematical modeling, dynamical systems, and scientific computation. His masters thesis was on computational geometry of moving interfaces. His dissertation research focuses on computational methods for modeling survival for patients with Cystic Fibrosis. He has been working on compiling recourses for the Heliostat Consortium website for CSP. He also has been contributing to the NIO code development along with developing a camera sensitivity project. Mike is a classically trained pianist and plays piano in his free time.

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Kyle Sperber
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National Renewable Energy Laboratory (NREL)

Mentor: Dr. Rebecca Mitchell

Project I Title: Develop Python Code Library for Heliostat Metrology in Concentrating Solar Power

Project II Title: Accuracy Analysis of the Camera Position Detection Algorithm

Project III Title: A Method of Calculating 2D Slope Error using a method of Beam Characterization System

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Abstract:

Project I
A method of using Concentrating Solar Power is to concentrate the power of the sun using heliostats, a parabolic mirror to focus sunlight on to a central power tower. However, due to weather, mechanical failures, and manufacturing imperfections heliostats become misaligned with the tower. Non-Intrusive Optical Metrology (NIO) is a method of using drones to conduct error analysis of a heliostat to verify its alignment with a tower. Through the development of NIO, a class library and a new software architecture design was needed to provide a user-friendly interface that optimizes the operation time and efficiency of the process. The result of this project created a software that reduces operation runtime, does not produce memory leaks or unnecessary memory allocation, and creates tools that are user-friendly.

Project II
A part of the NIO software is detecting corners to determine the cameras position. This is done so that error analysis based on the camera's position relative to the heliostat and tower can be done. However, to guarantee optimal corner detection a sensitivity test on the algorithm was ran on a variety of factors such as if other heliostats are in the frame, the lighting of an image of a target heliostat, and other scenarios that could mess with corner detection.

Project III
One of the error analysis techniques that NIO uses measures slope error, which is error that comes from point-wise mirror surface misalignment with the tower. A proposed method of calculating this error is by using the Beam Characterization System. Where a target on the tower is identified in the reflection of a heliostat surface. Then using that reflection, error can be calculated through reflection deviation from the ideal reflection point.

Bio:

Kyle is a senior at the Colorado School of Mines studying Computational and Applied Mathematics, and Physics. Kyle's academic interests include studying Non-Linear Differential equations in Electro-Magnetism, Thermodynamics, and Quantum Mechanics and the properties that arise in a system due to non-linearity. He is specifically interested in looking into plasma dynamics and conditions of stability. In his free time, he enjoys hiking, trail running, and climbing.

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Daniel Tsvankin
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National Renewable Energy Laboratory (NREL)

Mentor: Dr. Matt Muller

Project Title: HelioCon Components & Controls – Composites for Heliostat Structure Cost Reduction

Abstract:

Structures manufactured from steel comprise up to 40% of a CSP heliostat's cost. Composite structures represent an opportunity to reduce this cost, in addition to reducing life-cycle impacts of tracker fabrication and re-shoring these trackers' supply chain. A reference heliostat structural model has been created. An established roster of suitable metal alternative materials was considered including: glass, basalt, and carbon reinforced polymer (GFRP, BFRP, and CFRP). Additional alterations to the baseline design were explored to take advantage of composite materials' unique properties and further reduce cost to a two-axis tracker structure.

Bio:

Daniel is a graduate student at the Colorado School of Mines, interning at NREL year-round under Task 6 (Components & Controls) of the Heliostat Consortium and graduating this December with a Master's from the Advanced Energy Systems program. Prior to NREL, Daniel was a project engineer on custom containment systems for the nuclear and radiopharmaceutical industries and continues using his engineering experience and education to rehabilitate his fleet of project cars.

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Benjamin Bean
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Sandia National Laboratories (SNL)

Mentor: Dr. Randy Brost

Project Title: Universal Field Assessment, Correction and Enhancement Tool

Abstract:

In Concentrating Solar Power (CSP), small errors in heliostat pointing angles result in extended timelines during construction and lost efficiency during operation. In this talk I present an overview of previous work to measure mirror pointing angle error, and our team's approach, named UFACET, which improves on this work. UFACET utilizes a drone and imaging system to measure entire solar fields quickly in a non-intrusive way, and can take these measurements during both stages of a CSP plant's lifecycle. I describe the advancements that we have been making in this work, including computer vision, algorithm design, and building a robust code base for future development to be released as open-source software. By combing video data, drone GPS logs, and field information, we can anticipate heliostat locations in frame. Finally, I will give a brief overview of where this work is currently and what still needs to be completed.

Bio:

Ben started as an intern at Sandia National Laboratories since August 2022. He will be completing his Master's degree in Computer Engineering from the University of New Mexico in the fall semester and hopes to continue his work in CSP at Sandia afterwards. He comes with a background in software engineering for scientific and industry applications, ranging from embedded systems to web development. When he's not at work, you can find him programming for fun or spending time with his wife and their furry friends.

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Zachary Bernius
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Sandia National Laboratories (SNL)

Mentor: Dr. Ken Armijo

Project Title: Heliostat Components and Controls

Abstract:

The project's focus is the components and controls of the heliostats. The two main goals for this are to refurbish all 218 heliostats with new components, such as new cRIOs, and create an algorithm to convert the heliostats from Open-Loop controls to Closed-Loop controls. Refurbishing the heliostats involves installing software, programming FPGAs, and later installing a cRIO in each heliostat. For the controls, the chosen method is Extremum Seeking Control (ESC). ESC is used to move to the optimum location when the optimum location moves around. This will allow the heliostats to compensate for differences in blueprint locations and actual locations, differences in mirror curvature, etc. Essentially, ESC allows the heliostats to compensate for unknowns and disturbances that the Open-Loop controls do not account for. After this calibration, it will be possible to move to Model Predictive Control in order to optimize power production and heat flux for more efficient power generation and testing.

Bio:

Zachary Bernius is currently attending the University of New Mexico for a master's degree in Mechanical Engineering. His master's thesis focuses on the Extremum Seeking Control (ESC) of the heliostats. He earned his B.S in Mechanical Engineering in May 2023 and in the same month started as a graduate intern at the National Solar Thermal Testing Facility (NSTTF) at Sandia National Laboratories (SNL). He enjoys working at the NSTTF because of the contributions to renewable energy. Outside of working at SNL, his interests include playing volleyball, lifting, and enjoying the outdoors.

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Haden Harper
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Sandia National Laboratories (SNL)

Mentor: Dr. Ken Armijo

Project Title: Heliostat Components and Controls

Abstract:

The project focuses on Concentrating Solar Power Heliostat Components and Controls. The goal of this work for HelioCon is to evaluate different options for Closed-Loop controls for a Heliostat field. I was tasked with this project because of my background in control systems. With this I have been working on using the Extremum Seeking Control algorithm that has been used in a wide variety of industries. This algorithm will be used as our calibration algorithm to eventually transfer this over to Model Predictive Control which will be the full-scale algorithm. The goal of our algorithm is to keep the capability of using many different sensors for feedback data such as Infrared Cameras, Thermocouples, Heat Flux Sensor, etc.. This research is essential for offering open-source data and algorithms for other CSP organizations to use as needed.

Bio:

Haden Harper is a Mechanical Engineering Masters Student at the University of New Mexico. He earned his B.S in Mechanical Engineering in 2022. He started as a graduate intern at the Concentrating Solar Department of Sandia National Laboratories in April of 2023. His Master's thesis focuses on Closed-Loop controls applications for heliostat fields. Haden has always had a mind for research and loves the hands-on aspects of his projects at Sandia. Aside from his scientific interests he likes being active, hanging out with his dog, and traveling.

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Madeline Hwang
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Sandia National Laboratories (SNL)

Mentor: Dr. Randy Brost

Project Title: Heliostat Motion Control

Abstract:

Heliostats reflect and concentrate sunlight onto a receiver to generate thermal energy. This requires heliostat motion to accurately track the sun, making motion a basic capability that must be trusted to ensure efficient power output. The optics team at Sandia's NSTTF is developing a ground-truth measurement technique using a laser mount and target images to determine a heliostat's motion repeatability, dynamic response, and the heliostat's motion characteristics. Understanding heliostat motion gives researchers more information about their limitations and a better ability to utilize heliostats for improved power output. In this presentation I will describe the laser system we developed for these measurements.

Bio:

Madeline Hwang is a current undergrad student studying electrical engineering and psychology at the University of New Mexico (UNM) and a year-round intern developing heliostat management and maintenance procedures at NSTTF. Working with the staff at NSTTF, she has grown more passionate about renewable energy technologies to combat climate change.

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Tristan Larkin
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Sandia National Laboratories (SNL)

Mentor: Dr. Randy Brost

Project Title: OpenCSP Python Library

Abstract:

A variety of powerful, but disjoint, software tools are available for groups to research, develop, and produce CSP systems. Many of these tools were developed with software that has been rewritten time and time again, so a library that can be used to develop future tools under a common base that already includes many common features pre-written and thoroughly tested presents itself as a useful addition to the software space. The CSOL team at the NSTTF has developed multiple tools that do not easily “talk” with each other, but a common library opens the opportunity for easy communication between different programs that use the same code. OpenCSP is a developing library written for Python and already has various core features for CSP software, such as simulating heliostats and ray tracing. CSOL has already begun to incorporate this common library into the existing SOFAST tool, which will allow SOFAST outputs to become mirrors or heliostats in the OpenCSP base classes. OpenCSP will help build towards coherency in the CSP software space, allowing CSP software developers to focus on problems that do not already have solutions.

Bio:

Tristan Larkin is entering his senior year as a Physics and Computer Science student at the University of New Mexico. He has been an intern at Sandia National Laboratories’’ National Solar and Thermal Test Facility for just over a year focusing on writing Python code for the OpenCSP project.

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