Thermodynamic Balance Control of Biosphere 2’s Landscape Evolution Observatory

Project Description

- Optimization of the thermodynamic balance control for Biosphere 2’s Landscape Evolution Observatory.
- LEO consists of three adjacent greenhouse-like bays, each containing their own artificial landscape.
- LEO itself contains over 1800 individual sensors to monitor the water, carbon, physical, chemical and biological evolution of the landscapes.
- The biological communities in the LEO experiments are incredibly temperature sensitive, so accurate thermodynamic controls are vital.
- Biosphere 2 technicians manually adjust thermodynamic systems based on observed conditions without an underlying methodology.

Scientific Challenges

- Currently there is no model for the thermodynamic balance control of greenhouse-like structures similar to LEO.
- Data acquisition and integration from Biosphere 2 into a functioning model.

Application

- Providing a functioning model allows Biosphere 2 to optimize the temperature of the soil, which in turn improves the accuracy of LEO and all related current and future experiments.

Team Members:

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The Model

Our model is a system of differential equations relating dirt and air temperatures together based on Newton's Law of Cooling:

\[
\frac{dT}{dt} = (a_1 \cdot G + k_1 \cdot (A - T)) \\
\frac{dA}{dt} = (a_2 \cdot G + k_3(H - A)) + k_2 \cdot (T - A) + k_4(B - A) + k_5 \cdot A
\]

T = Dirt Temperature  
G = Global solar radiation  
A = Air temperature  
H = Air Handler  
B = Ambient Temperature

This system of differential equations was then recreated as a simulation with MATLAB and solved via the forward Euler method in 15-minute time steps to match live data from Biosphere 2.

Initial model parameters \(a_1, a_2, k_1, k_2, k_3, k_4, k_5\) were calibrated by hand to achieve average errors of approximately 2 °F for the soil temperature and 5 °F for air temperature.

Results

1. Created a system of differential equations to describe the thermodynamic balance of the greenhouse-like environment of the LEO experiment.
2. Created a simulation and solved the differential equation via forward Euler Method in MATLAB to mirror the behavior of live LEO data.
3. Optimized the parameters of the equations via nonlinear least squares optimization algorithm, which further refined the results to yield average errors of 1.3013 and 2.8539 °F respectively for air and soil.
4. Tested the optimized model on a variety of weather conditions and seasons to ensure generalized accuracy of the LEO simulation throughout the year.

Glossary of Technical Terms and Equations

- Newton’s Law of Cooling: \( \frac{dT}{dt} = k(M - T) \)
- Forward Euler Method: \( y_{n+1} = y_n + h(f(y_n)) \)
- Non-Linear Least Squares Optimization: \( \min f(x) = \sum |h_i(x)|^2 \)

References


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