

Dependable Long-Term Operation of Solar Energy Harvesting Networked Embedded Systems

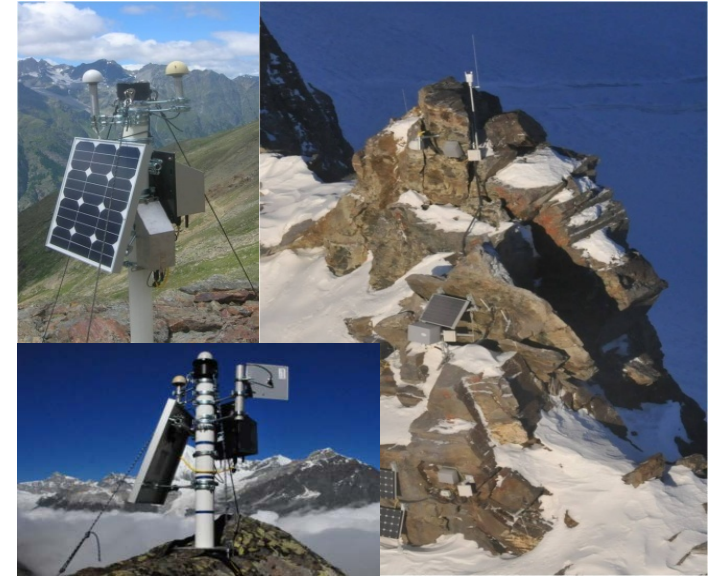
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> Motivation & Research Question

How to achieve dependable long-term operation of solar energy harvesting networked embedded systems?

Motivation: Long-term environmental monitoring in extreme environments needs renewable energy sources.

Problems: Highly variable non-deterministic harvested energy. Dynamically balance use of energy and storage



> Methodology and Results

How can we guarantee the real-time execution of system tasks under energy harvesting?

How can we optimally provision the energy harvester and energy storage while guaranteeing the system utility?

How can we optimally control the energy flow while avoiding breakdowns and optimizing the system utility?

Power Sub-System Provisioning [1]

Approach:

- Approximate the annual energy input trend with an adjusted astronomical model.
- Use balancing equations (surplus vs. deficit and total energy) to dimension battery capacity and solar panel size.

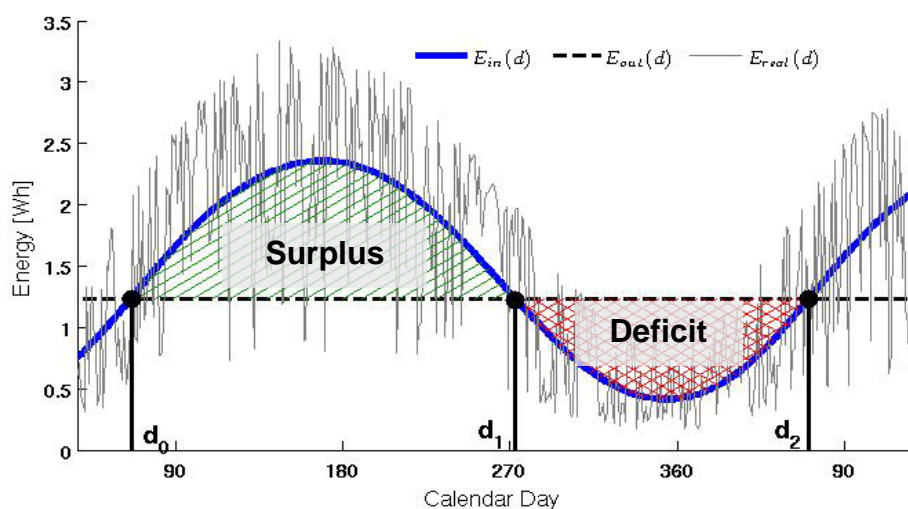
Dynamic Power Management [2,3]

Approach:

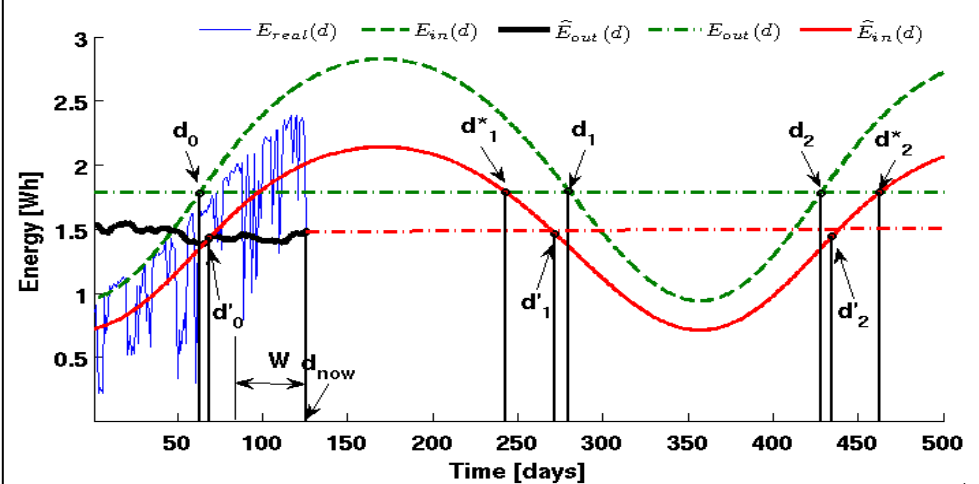
- Finite horizon control of usable energy.
- Run-time adaptive estimation based on the design-time astronomical model.
- Control duty cycle based on difference between actual and estimated harvested energy.

Validation

X-Sense [4]: Sensing in extreme environments (rock glaciers in high alpine regions) with GPS. Multi-year collected solar energy harvesting data.



→ Zero downtime, up to 53% smaller batteries than baselines



→ 2x higher minimum duty-cycle, 1.7x higher average duty-cycle than baselines

> Recent Publications

- [1] B. Buchli, F. Sutton, J. Beutel, L. Thiele: Dynamic Power Management for Long-Term Energy Neutral Operation of Solar Energy Harvesting Systems. **SenSys** 2014
- [2] B. Buchli, F. Sutton, J. Beutel, L. Thiele: Towards Enabling Uninterrupted Long-Term Operation of Solar Energy Harvesting Systems. **EWSN** 2014
- [3] B. Buchli, P. Kumar, L. Thiele: Optimal Power Management With Guaranteed Minimum Energy Utilization For Solar Energy Harvesting Systems. **DCOSS** 2015
- [4] J. Beutel, B. Buchli, F. Ferrari, M. Keller, L. Thiele, M. Zimmerling: X-Sense: Sensing in Extreme Environments, **DATE** 2011