

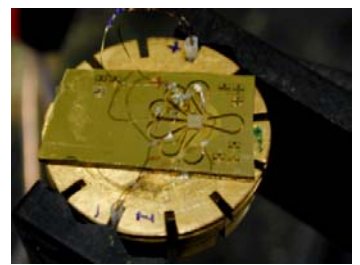
# Energy Harvesting Support for Sensor Networking

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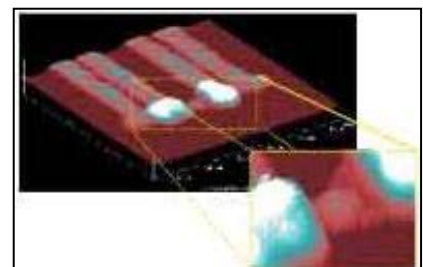
**Introduction:** Exploit Environmental Energy to Increase System Lifetime or Performance

## Energy Harvesting

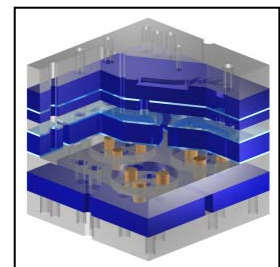
- System life and performance can improve with extra energy
- Several harvesting technologies available/emerging



Thermoelectric (DARPA, JPL, CalTech)



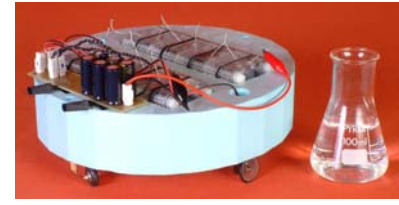
EM Direct Conversion Device (DARPA, ITN)



Micro-Hydraulic Transducer (DARPA, MIT)



Solar Cells



BioFuel, (IASL, UWE-Bristol)

- Ultimate goal - Deployment of self-sustained sensor network

## Managing Environmental Energy

- At the node level
  - Scale performance as per energy availability.
  - Schedule tasks optimally in space and time
- At the network level
  - Distribute tasks to nodes with more energy
  - Choose communication routes that maximizes system lifetime

**Problem Description:** Sensor network has limited lifetime when running on batteries

- Enable sensor nodes to scavenge energy from its environment.
- Need distributed method to learn the environmental energy opportunity and adapt global task sharing.

**Proposed Solution:** Energy Harvesting Support for sensor network.

## Harvesting Theory

**Definition:**  $E(t)$  is a  $(\rho, \sigma_1, \sigma_2)$  source if for all  $T$ :

$$\int_0^T E(t) dt \geq \rho T - \sigma_1 \quad \text{and} \quad \int_0^T E(t) dt \leq \rho T + \sigma_2$$

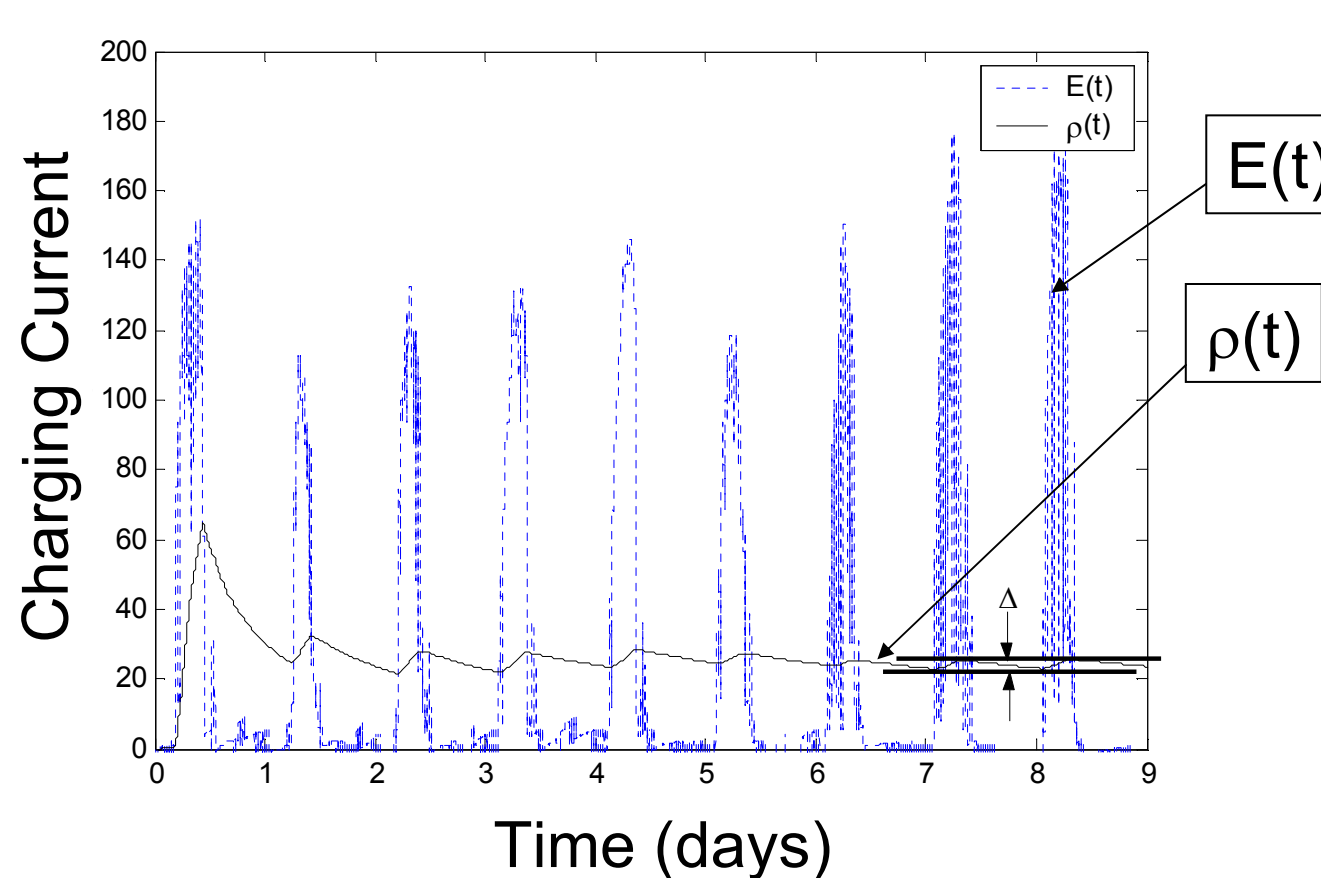
**Theorem 1 (Optimal Achievable Performance):** If

- a system is powered by a  $(\rho, \sigma_1, \sigma_2)$  source
- has energy storage capacity  $\geq (\sigma_1 + \sigma_2)$
- operates at constant power level  $\rho$

then it utilizes the energy source fully and can survive forever.

Theorem 2: Gives achievable performance when consumption rate not constant.

## Single Server Harvesting

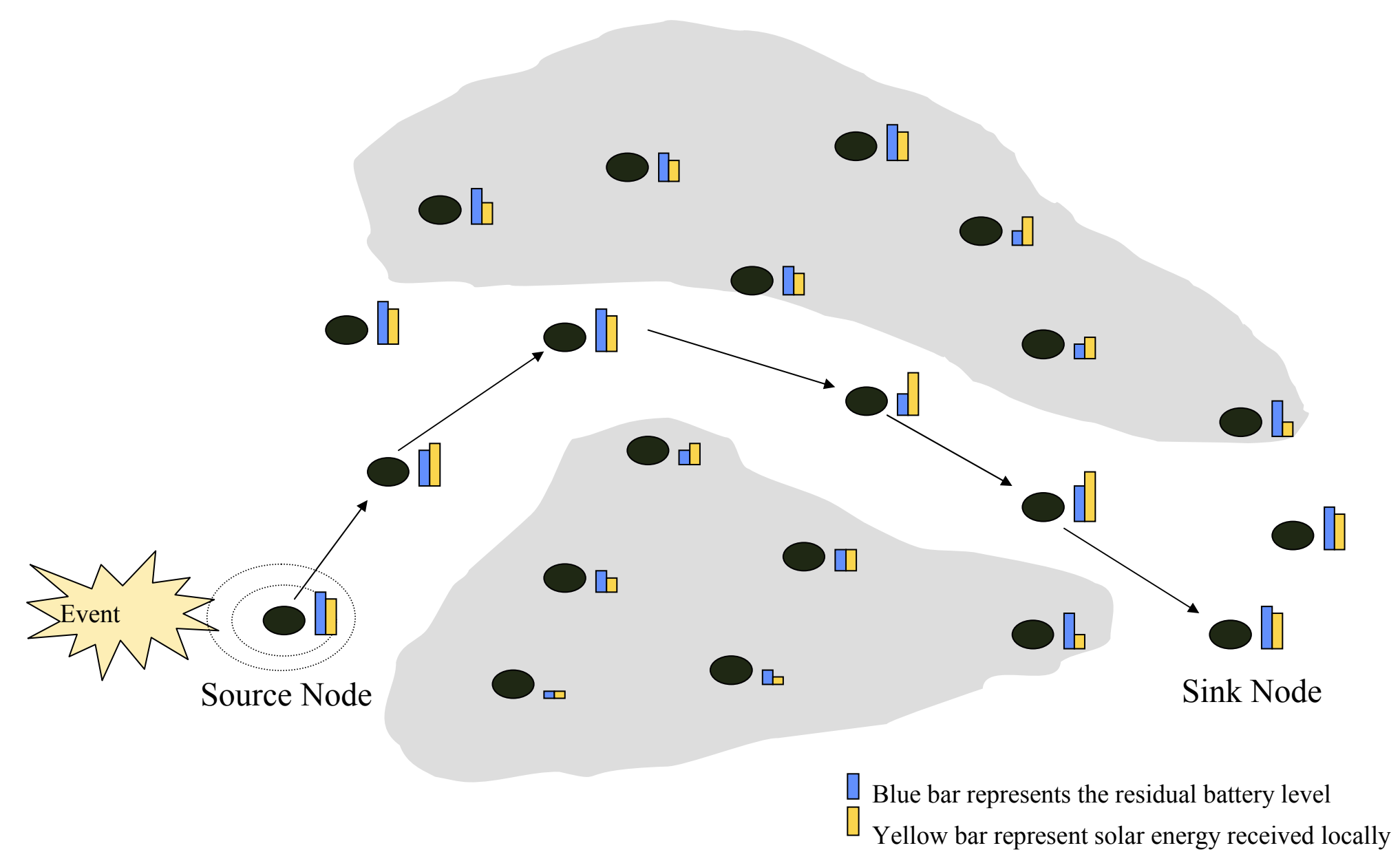


### Achieve energy neutral operation

- Learn theorem parameters from initial data
- Various means for performance scaling: Sleep cycle, Dynamic Voltage Scaling, Radio range control
  - Mote hardware: sleep cycle

## Environment Aware Routing

Utilize environmental information from Heliometer to choose most energy-efficient routes

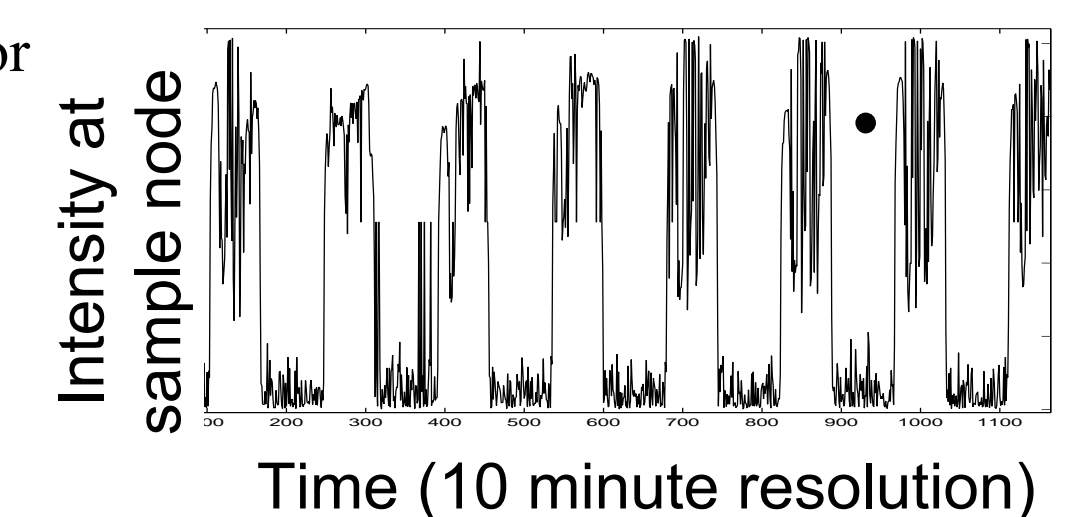
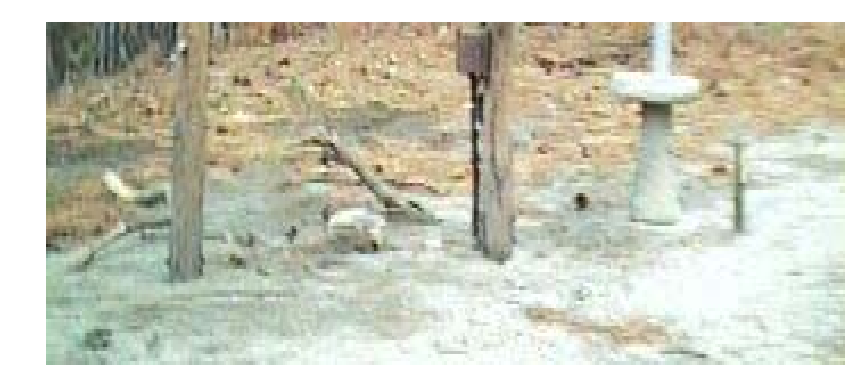


### •A modified version of Directed Diffusion

- Knowledge about neighboring nodes are sent along with Interest message from sink
- Event data back to sink through nodes with highest energy.
- Next-hop decision made independently at nodes
- Nodes with higher harvesting potential are used first.

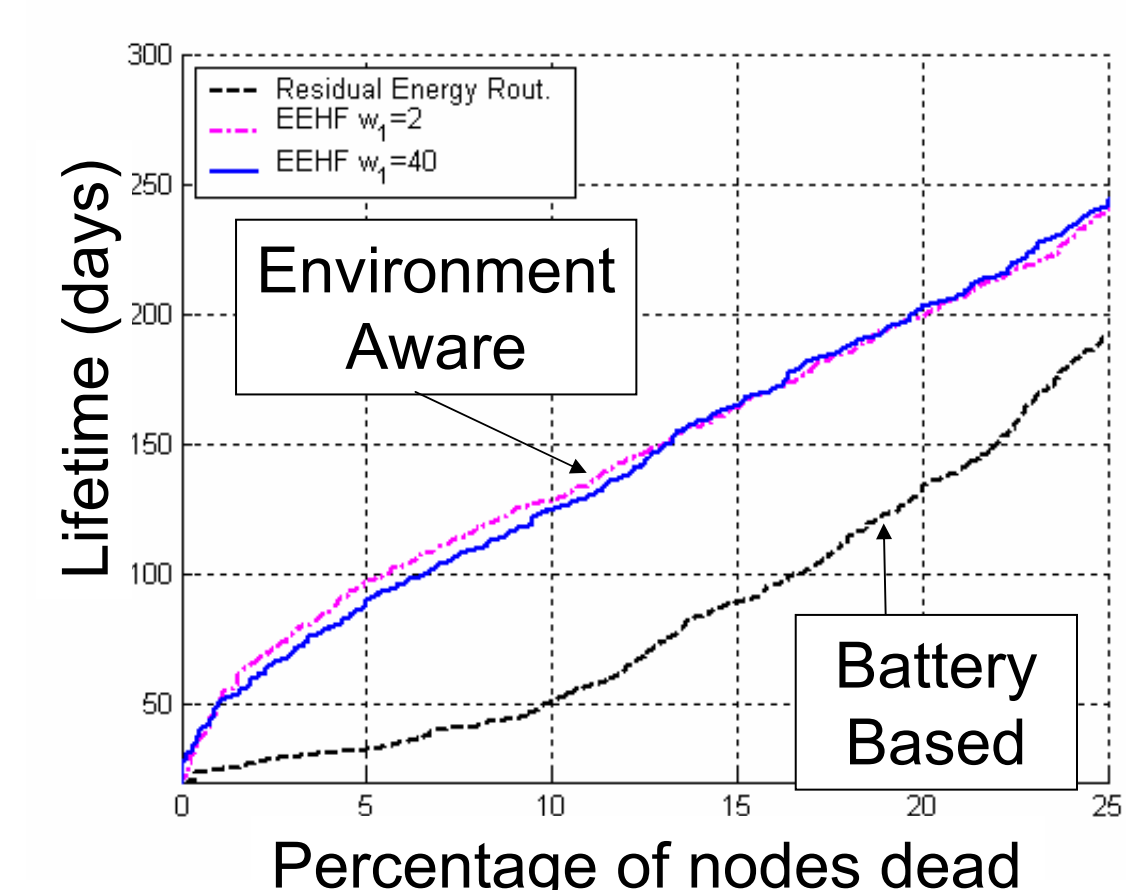
## Simulation Studies

- Light distribution collected at James Reserve
  - Data: 10 minute resolution for 40 days
- Light data used off-line to simulate a distributed sensor network (in NESLsim)



## Routing Results

- Route chosen based on environment and battery metric
- Avoids using nodes with no harvesting energy

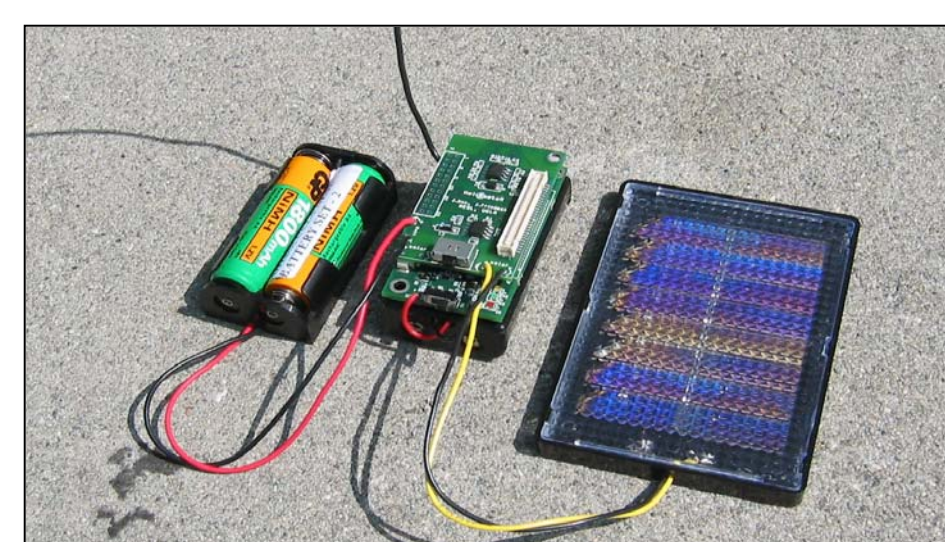
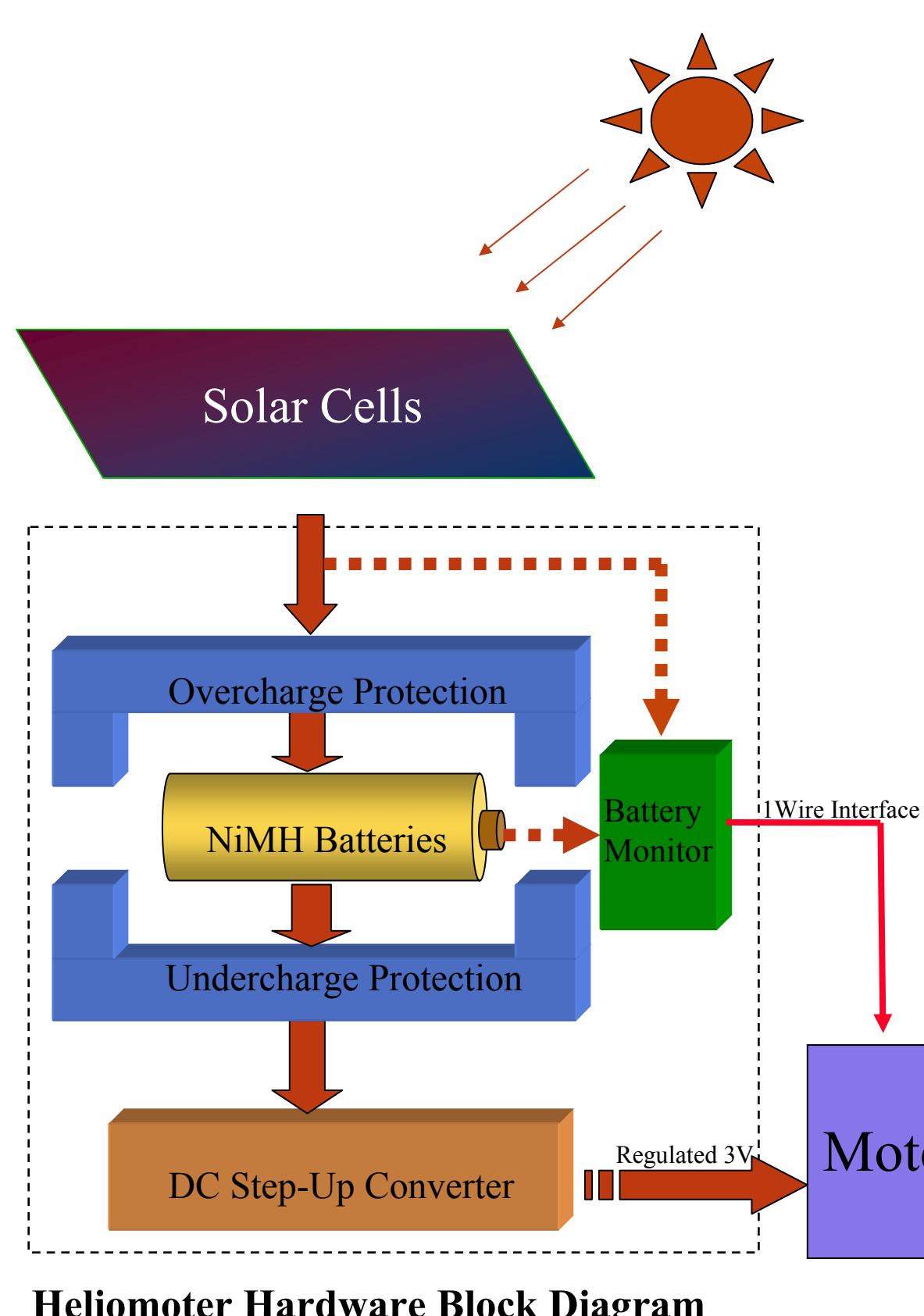


## Acknowledgements

- Jonathan Friedman
- Vijay Raghunathan

## Heliometer

A integrated solar energy harvesting and storage device for sensor network



### Overcharge protection

- Disconnect solar cells when batteries have reached their full capacity.

### Undercharge Protection

- Shut down DC Step-Up converter when batteries drawn below a present point

### Battery Monitor

- Communicate residual battery status and solar energy info with host sensor node

### DC Step-Up converter

- Provide a constant 3.0V output as per mote's operation requirement.