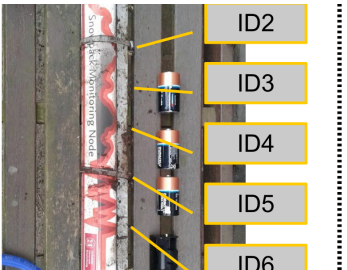
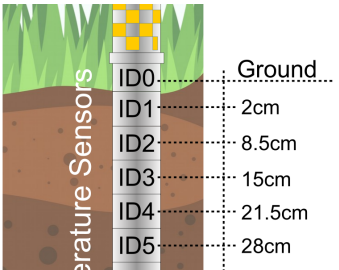
Technische Universität Braunschweig

Institute of Operating Systems and Computer Networks

Deployment





A Feasibility Study on Energy Harvesting from Soil Temperature Differences

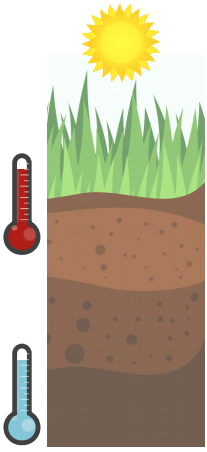
Sven Pullwitt, Ulf Kulau, Robert Hartung, Lars Wolf, 2018-11-04

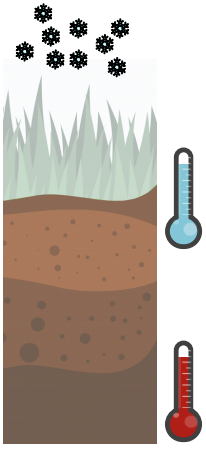
Smart Farming

Smart Farming: Challenges

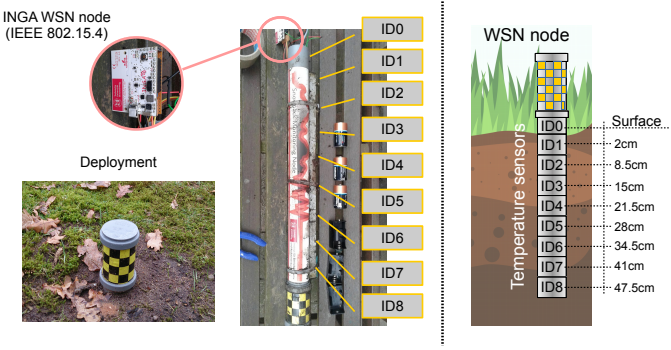
- Problem: Solar cells not possible
- Nodes near surface of soil
- Lots of dirt, no sun due to crops

Idea: Harvest from soil





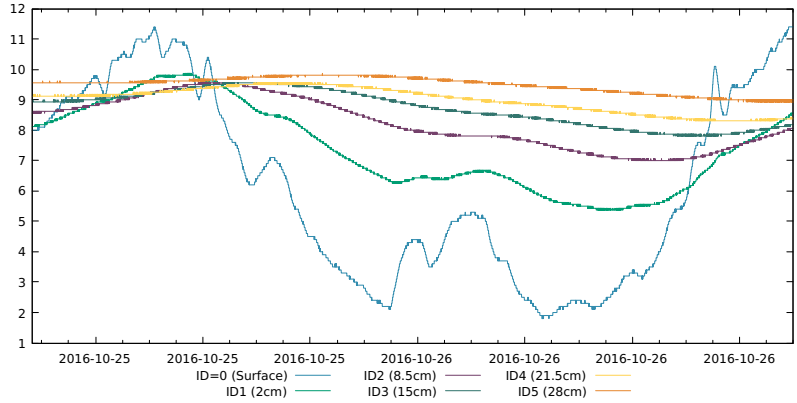
Setup



duration: 1 year, sample rate 10s, data are available[1]

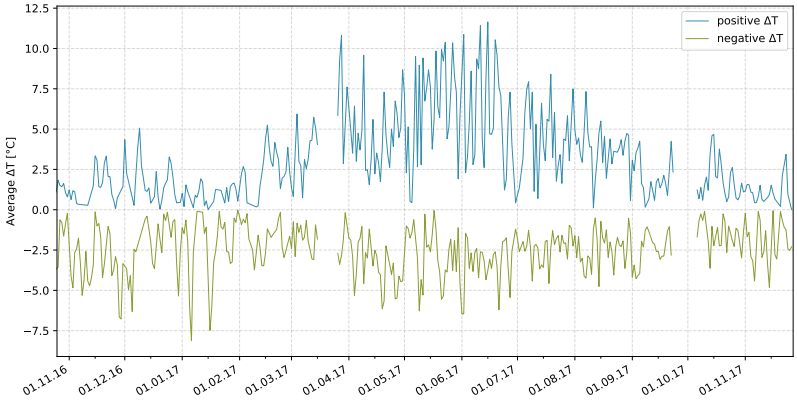
[1] https://www.ibr.cs.tu-bs.de/projects/reap/soil_temp.html

Examplary Data



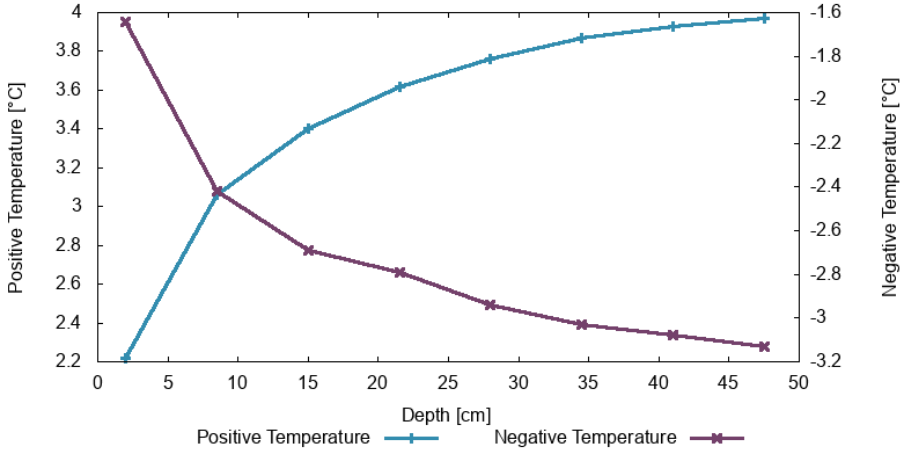
First week

Results

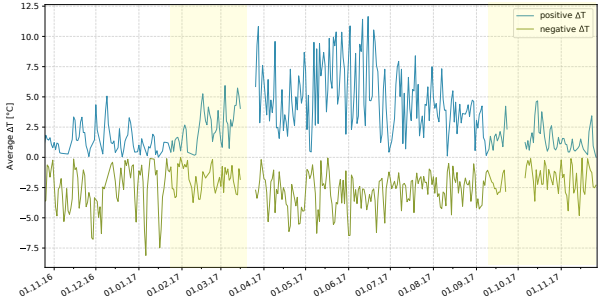


Gaps due to battery exchange

Temperature vs. depth

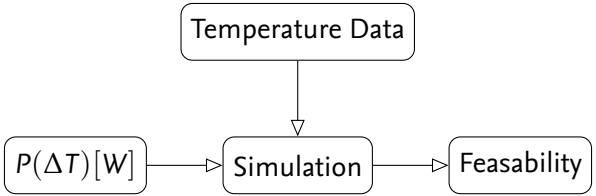


Conclusion

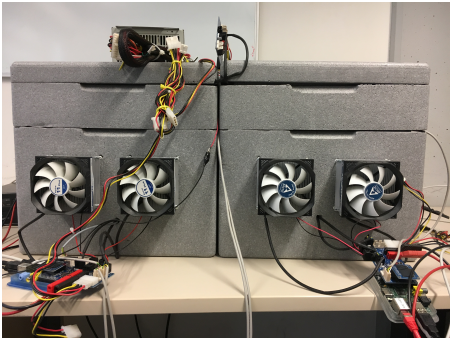


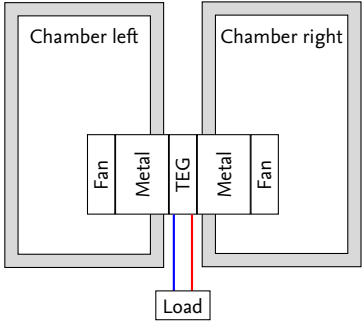
- Temperature differences of several degree every day
- Exception: transition period (spring, autumn)
- Q: can we actually harvest energy?

General Idea



Setup

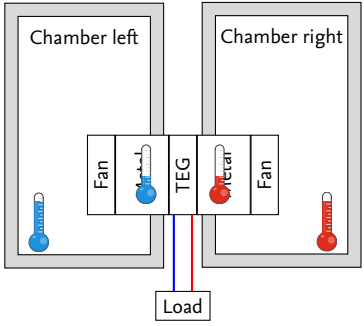




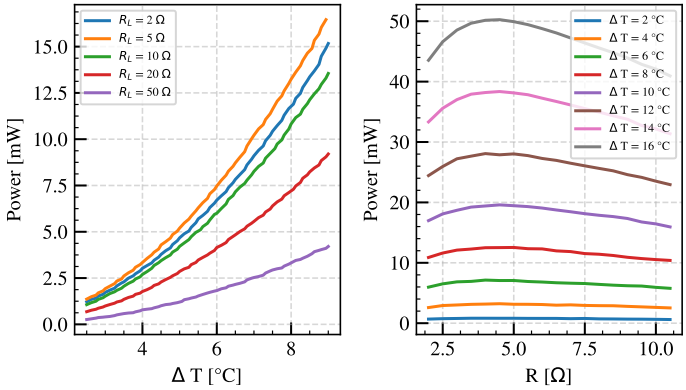
- How much energy can we produce?
- Electronic load to simulate harvester+microcontroller

Setup

- Fixed value for load, cycle through temperatures (10-50 °C)
- Constantly measure temperature
  - In chamber (T_C)
  - Near element (T_E)
  - But: $|T_C - T_E| \gg 0$
- Result: $|T_C - T_E| \to E$



Results



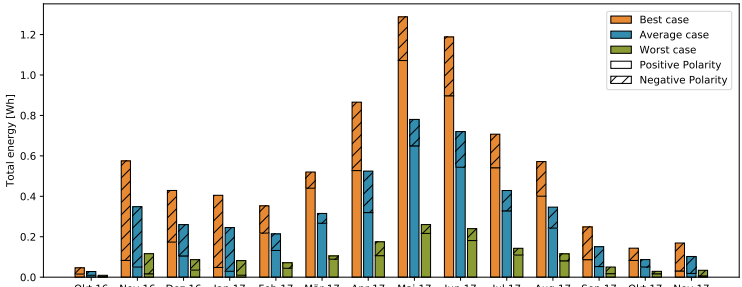
2nd Experiment: Fixed temperature, cycle through resistance (MPPT)

Harvesting Model

- Temperature gradient in chamber differs from the one at TEG
  $\Rightarrow$ factor h is introduced
- $P(\Delta T, h) = h \cdot (a \cdot \Delta T^2 + b \cdot \Delta T + c)$ [W]
  with TEG specific a,b and c
- Store harvested energy
- Estimate the energy collected by a simulated harvester

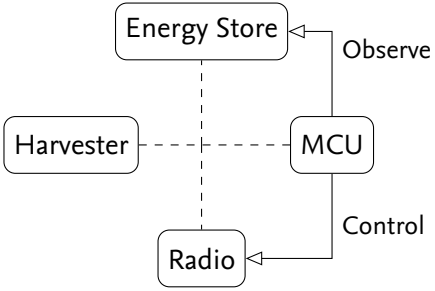
Harvestable energy with different efficiency η

Soil temperature experiment $\rightarrow$ harvested energy per month



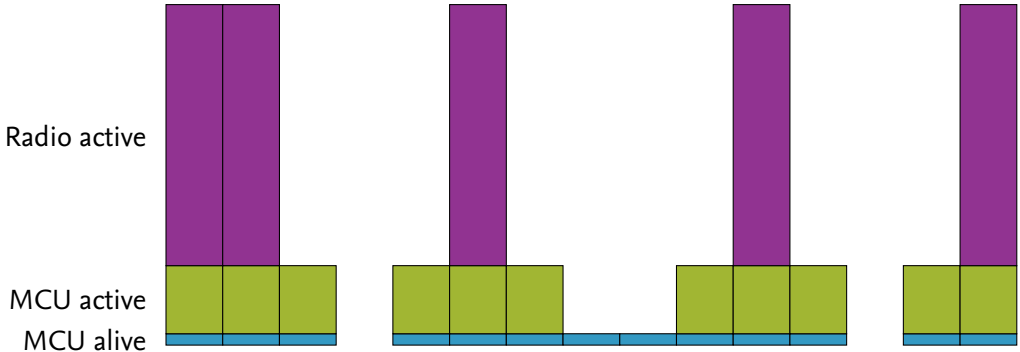
Best Case $\eta = 99\%, h = 99\%$
Average Case $\eta = 60\%, h = 41\%$
Worst Case $\eta = 20\%, h = 20\%$

Sample Application



- Simulate a virtual node
- Slots in simulation, where:
  - Energy is harvested
  - data is sensed, and (MCU active)
  - transmitted if possible (Radio active)
- Additionally, MCU can sleep (MCU alive)

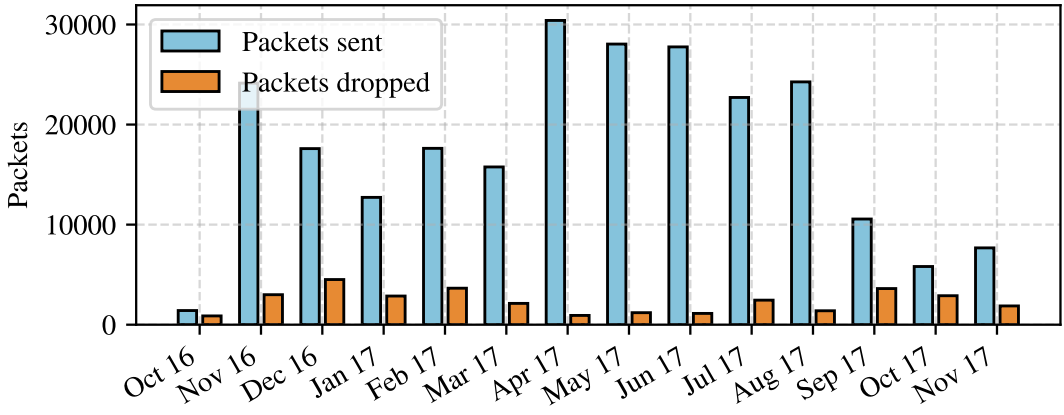
Slot Example



Active states

State is entered, if there is enough energy

Transmitted frames



Conclusion

- Long-term experiment with soil temperatures from 8 depths
- Temperature-controlled chambers with TEG to model harvestable energy from ΔT
- Simulated WSN Application:
  - 7.5 packets per hour in winter, 40 in summer
- Next step: deploy an actual system!