HSLU Hochschule Luzern

Fault Detection for Photovoltaic Systems on the Edge

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22. März 2022


CLEAN ME
PLEASE

Topics for today

Research Goals → Hardware & Data Collection → Machine Learning & Results → Future Work

Research Goals

Innosuisse - Swiss Innovation Agency

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

SmartHelio
www.smarthelio.com

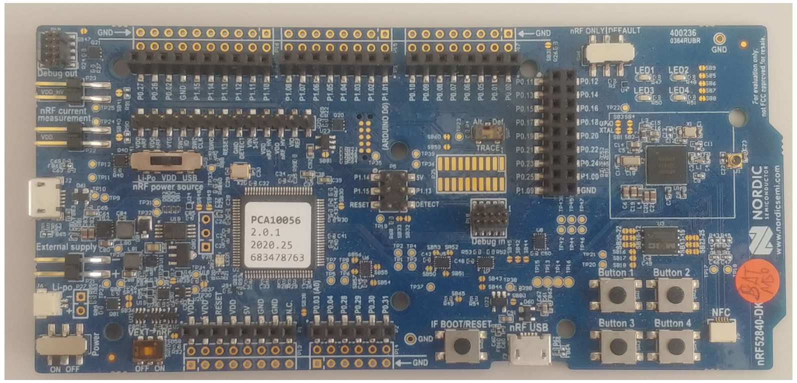
- Develop plug & play IoT sensor for data collection & inference.
- Fault detection within PV array data.
- Downsizing data at edge level to reduce data cost.
- Deployment of ML model on MCUs.

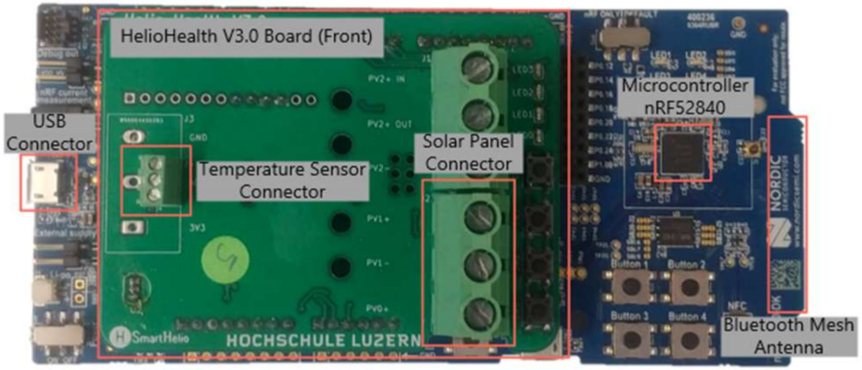
Innosuisse funded project (45299.1 IP-EE Intelligent SmartHelio Mesh)

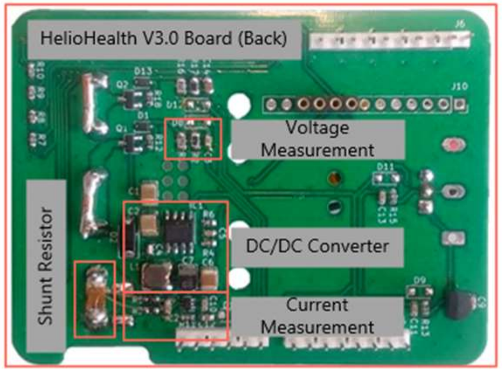
Sensor Hardware

- Scalability: Mesh Communication
- Plug & Play
- Low-cost & low-power

• Nordic Semiconductor nRF52840
• Cortex M4F, 1MB Flash, 256kB RAM
• Integrated BT Mesh (2.4GHz) Transceiver

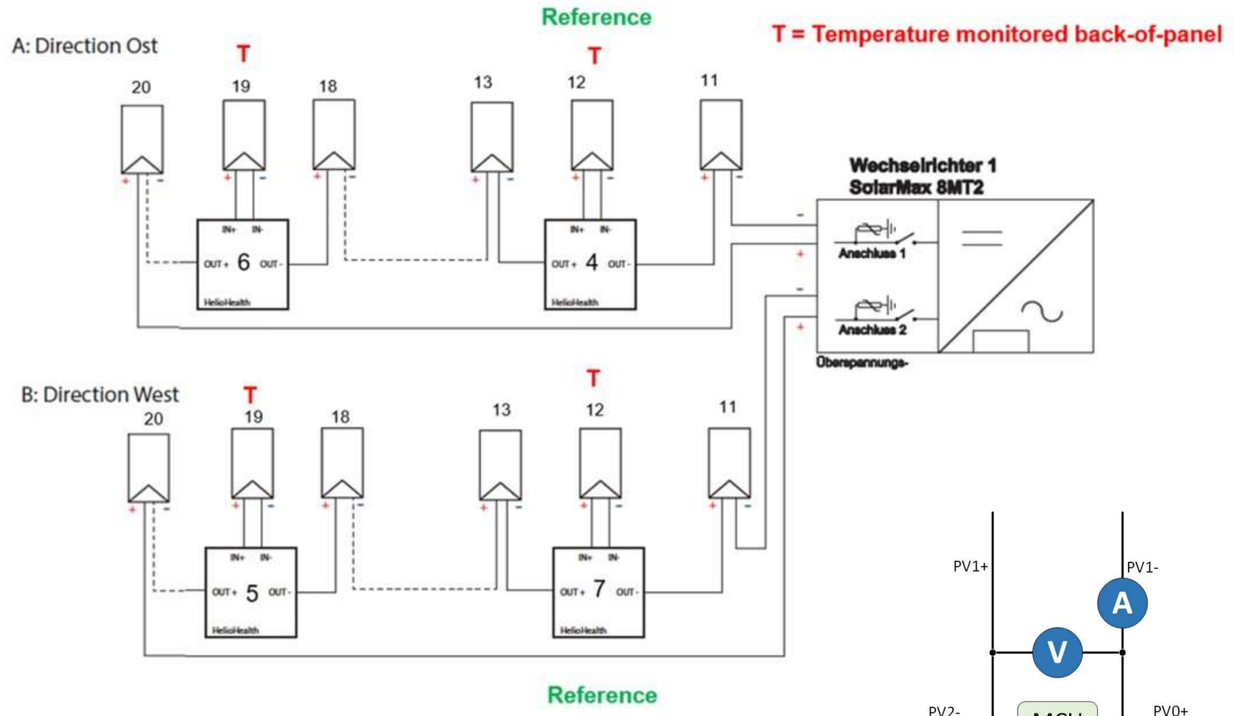


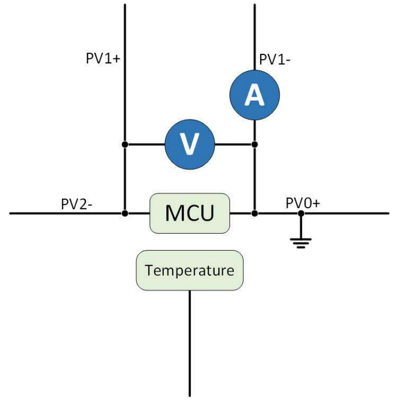


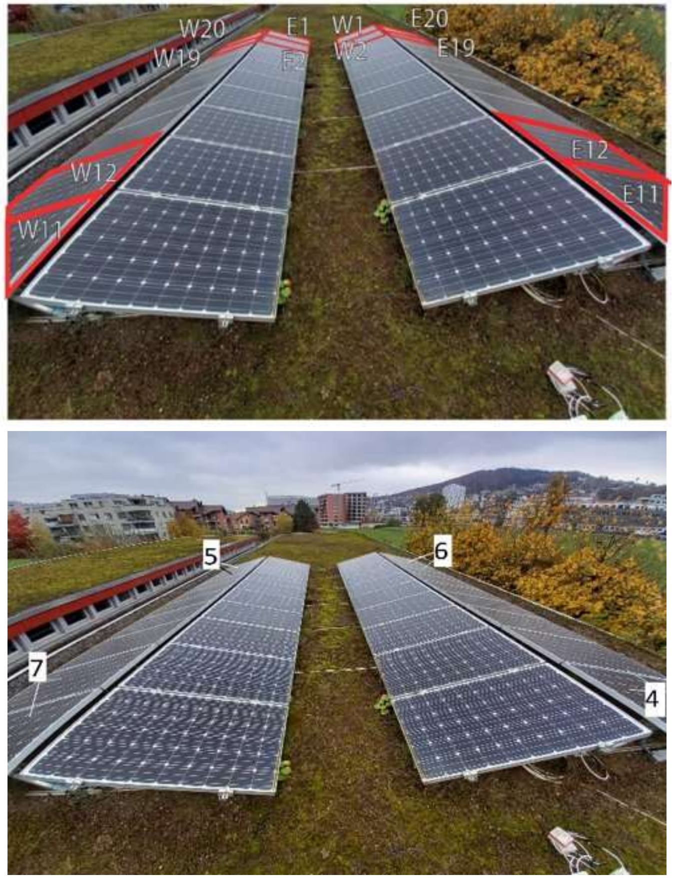


Measurements:
-Voltage
-Current
-Temperature

HSLU PV System







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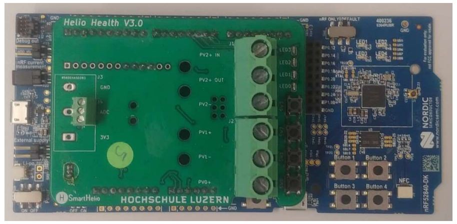
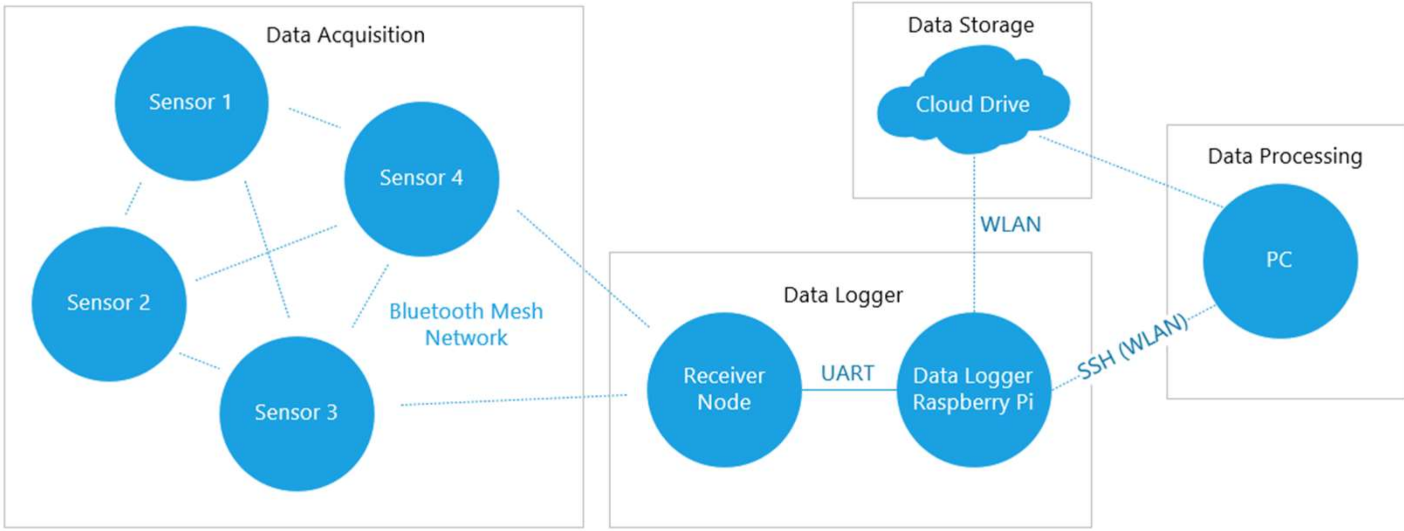
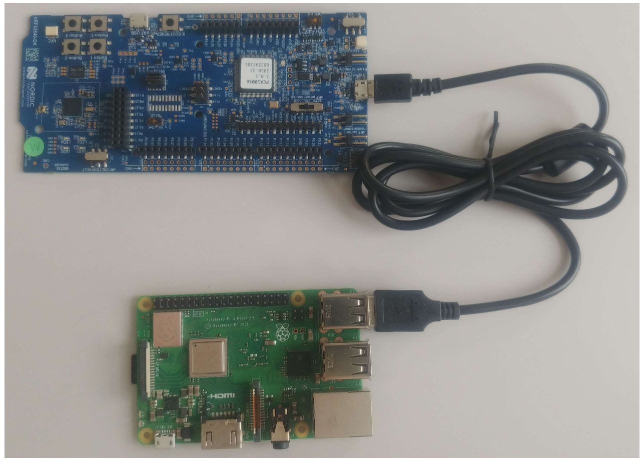
Installation

System Architecture for Data Collection for ML

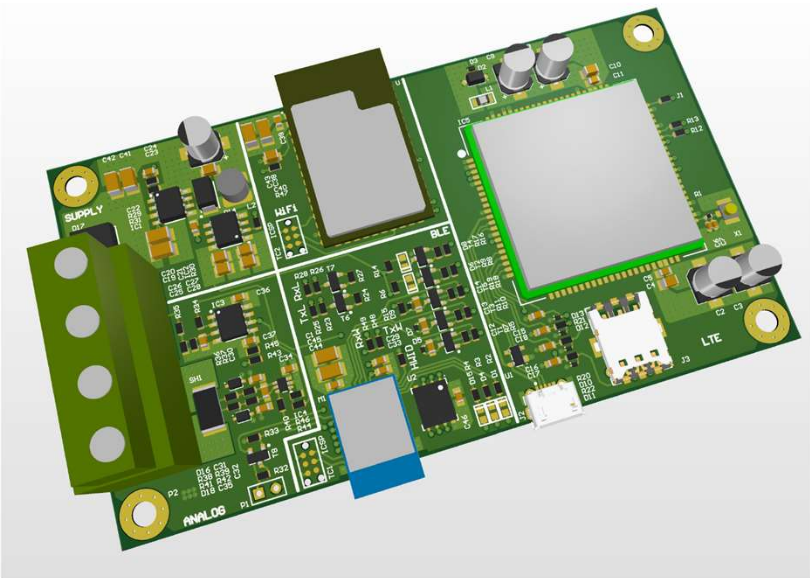


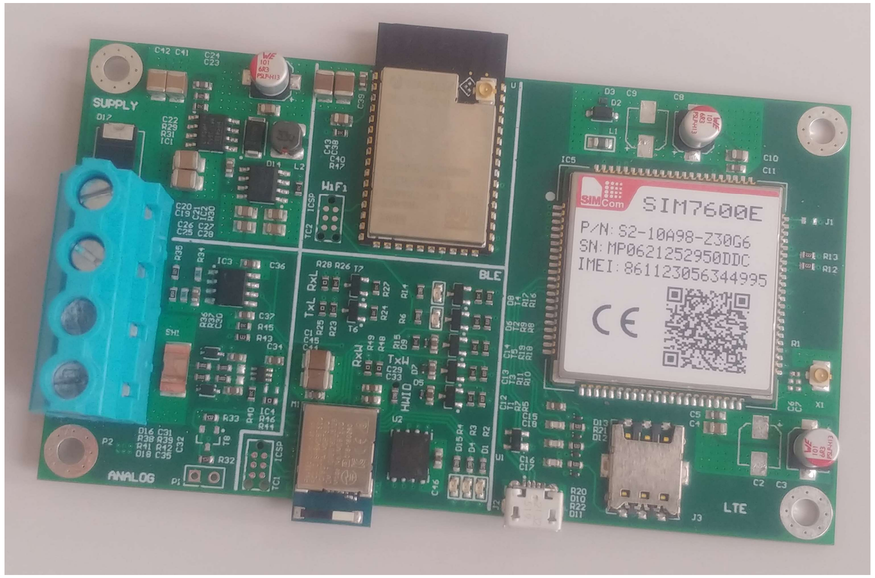


Almost 1 year of data ~10GB

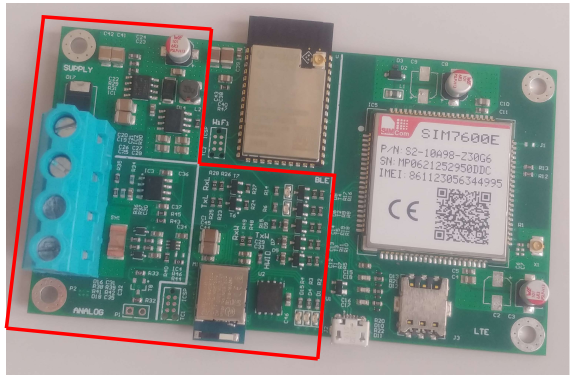


PCB

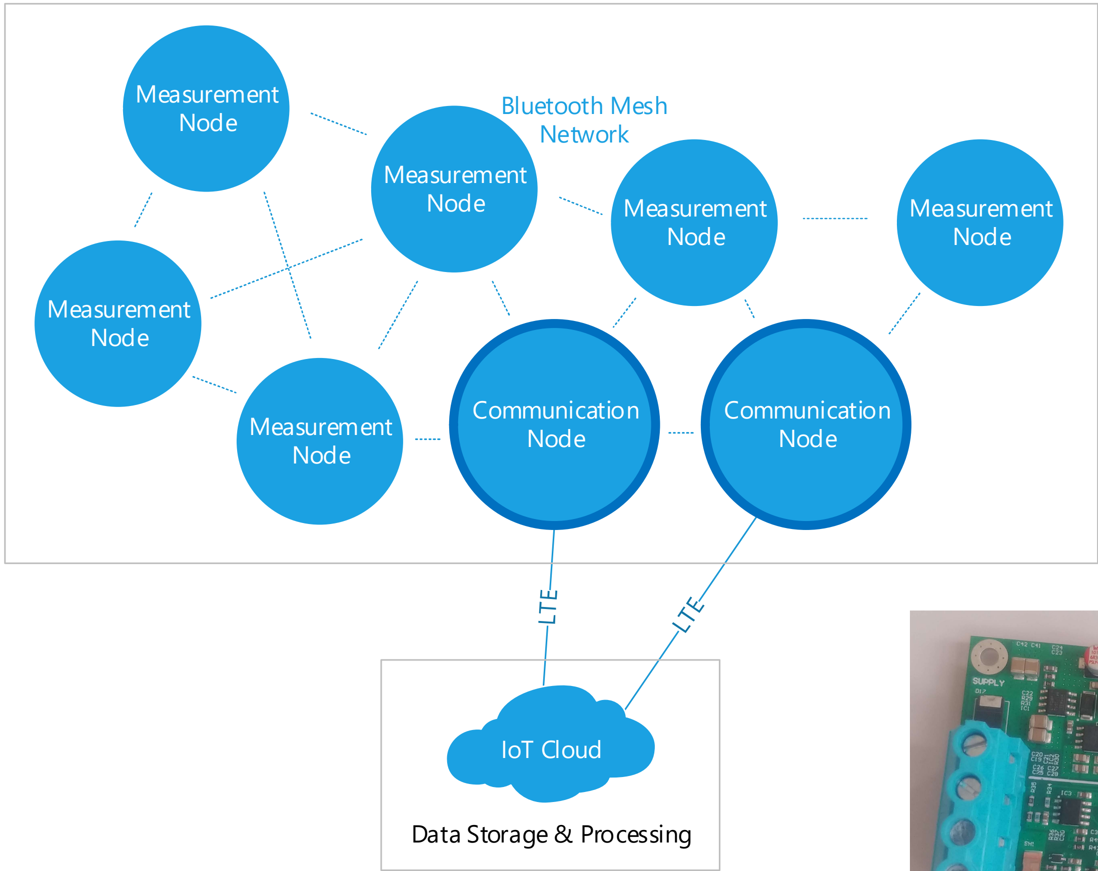

SUPPLY
WiFi
BLE
LTE
ANALOG


SUPPLY
WiFi
BLE
LTE
ANALOG
SIM7600E

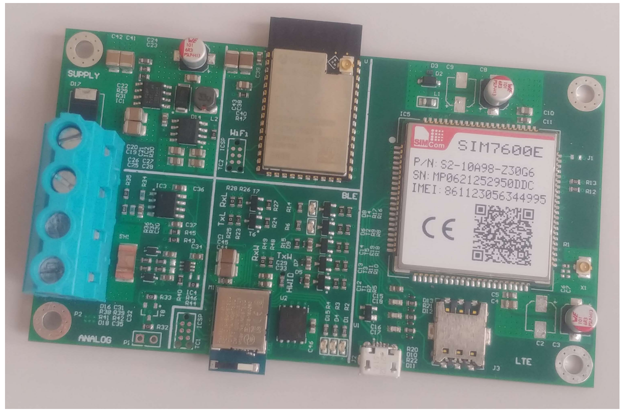
Final Architecture



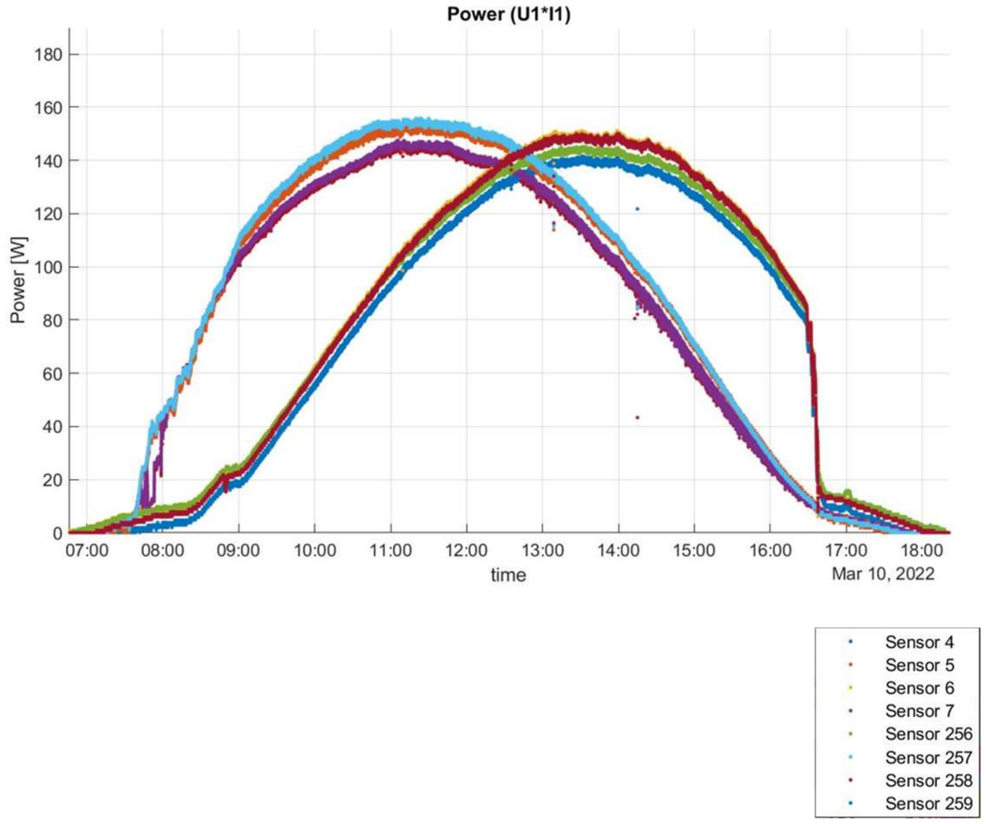
Measurement Nodes:
Bluetooth Mesh

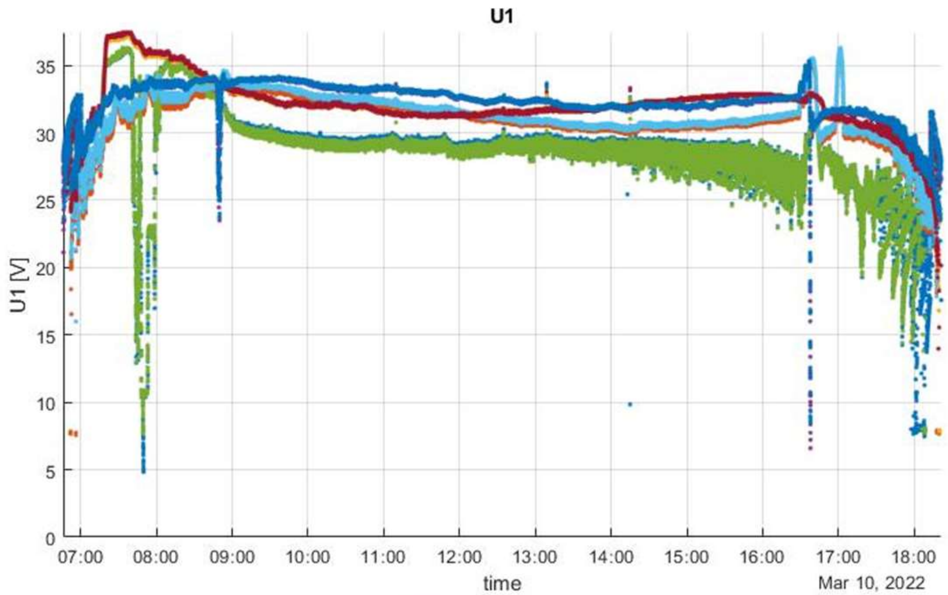


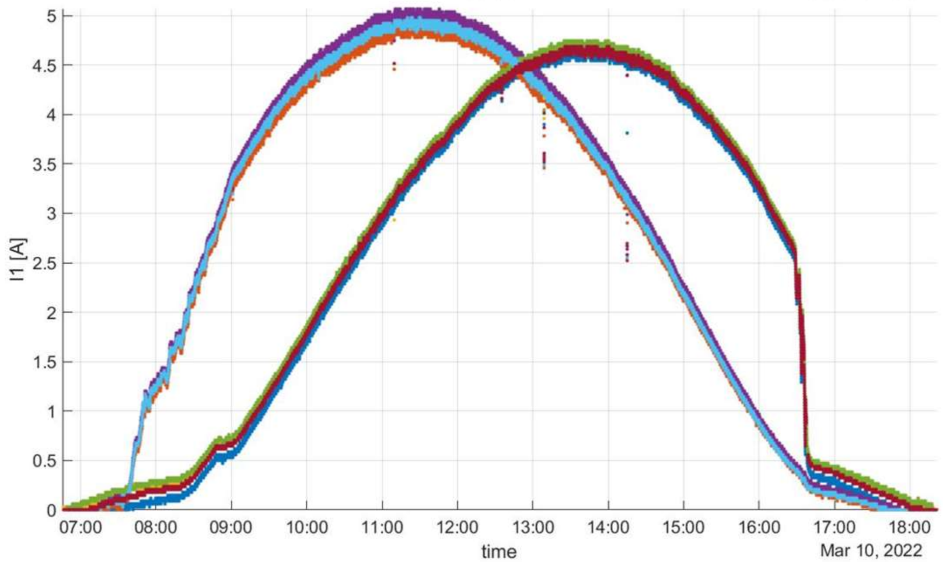
Communication Nodes:
Bluetooth Mesh
+ LTE



Data Sample 10.03.2022







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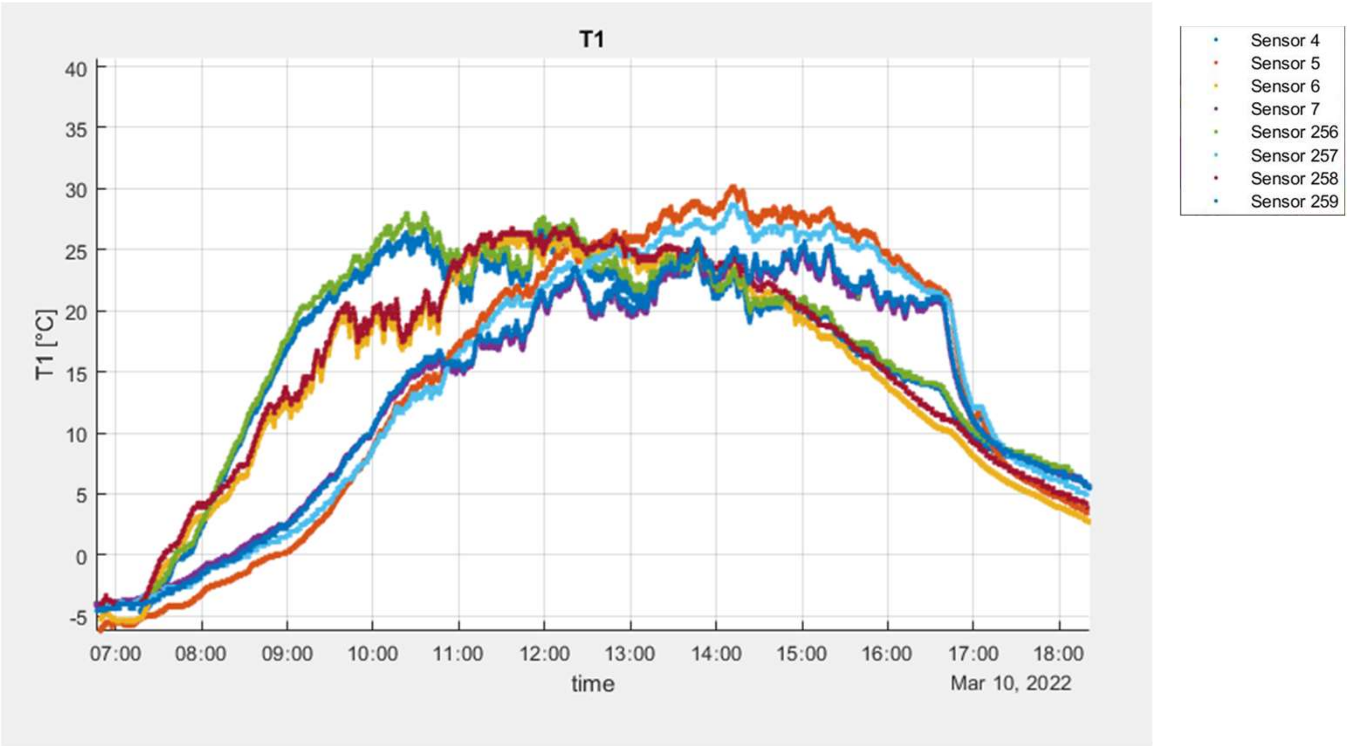
Temperature 10.03.2022



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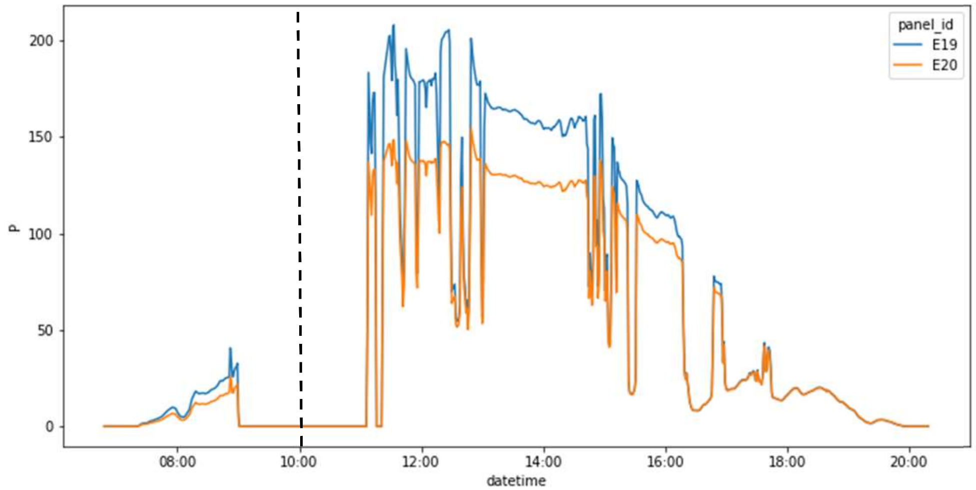
Controlled Fault Application

- No Fault
- Connector Failure
- Object Shading
- Partial Soiling
- Partial Shading
- Short Circuit Bypass Diode
- Soiling on Border

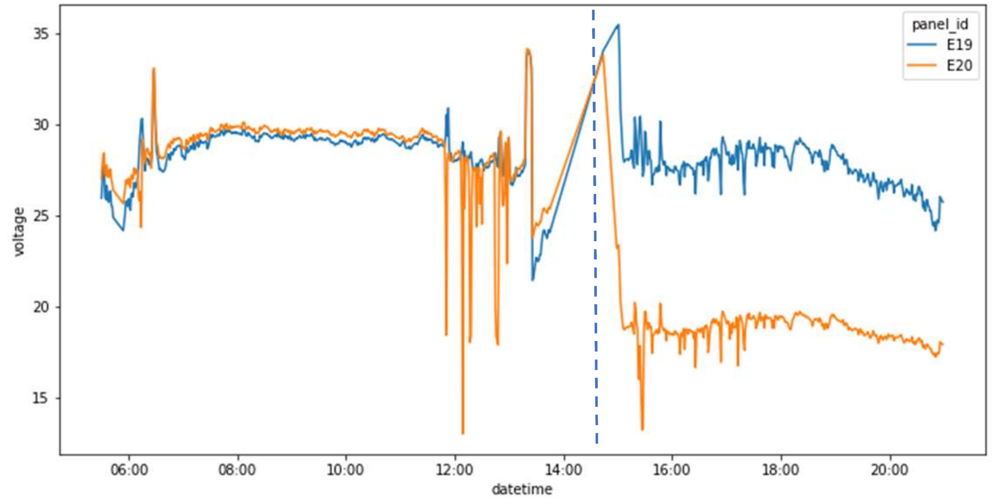
Challenges Hardware & Data Collection

- Powered by solar panel only
- Receiver node placement (Indoors – Blinds to North)
- Cloud communication for global deployment
- Access to array is difficult

Effect of faults on power and voltage characteristics



Connector Failure (23.08)



Short Circuit Bypass Diode (05.07)

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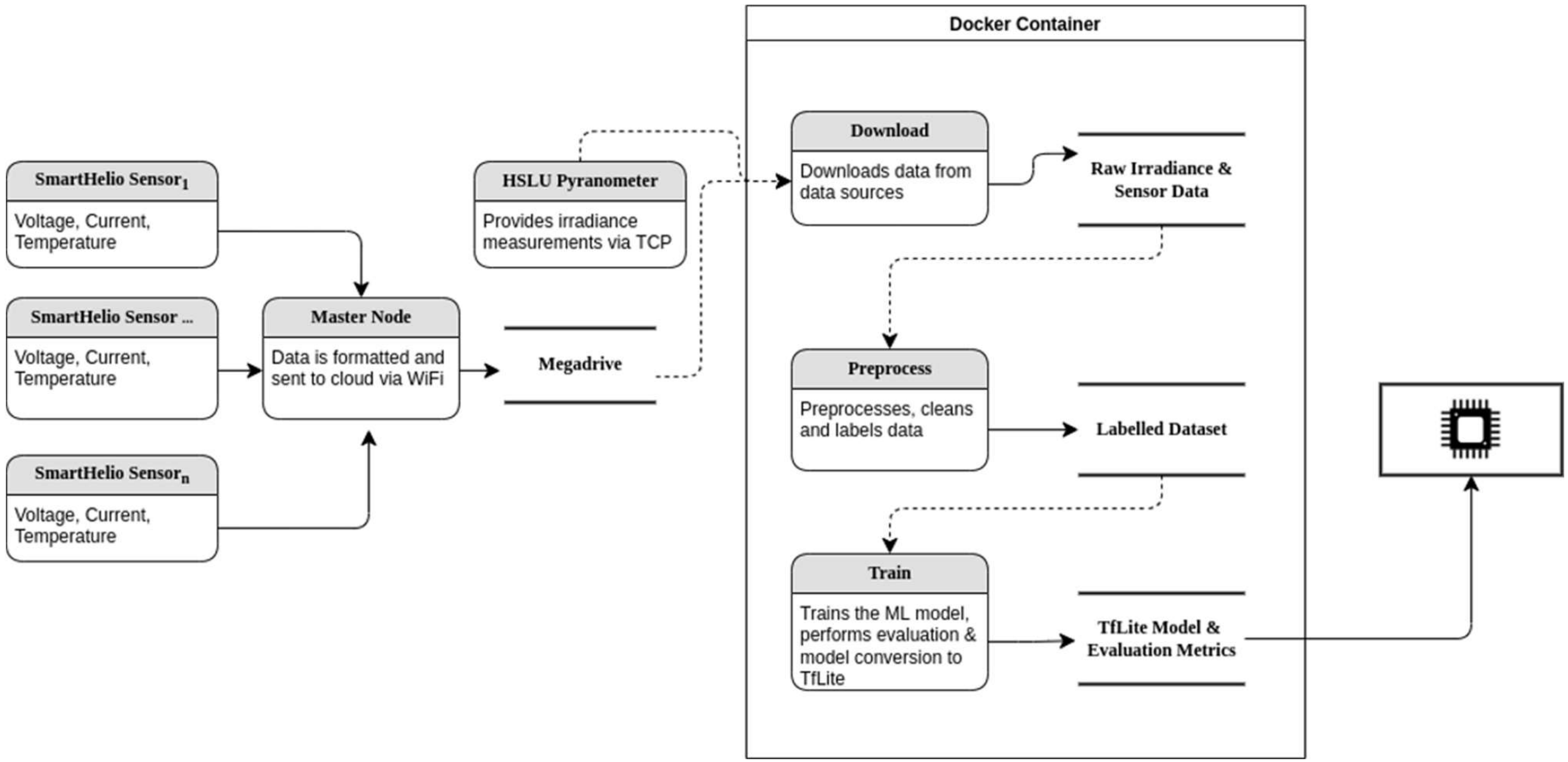
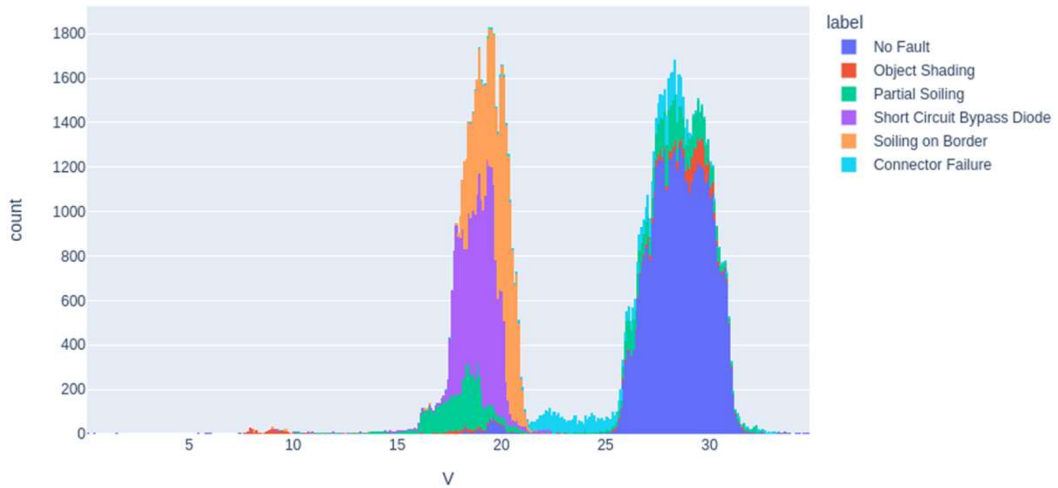
Machine Learning Pipeline Overview

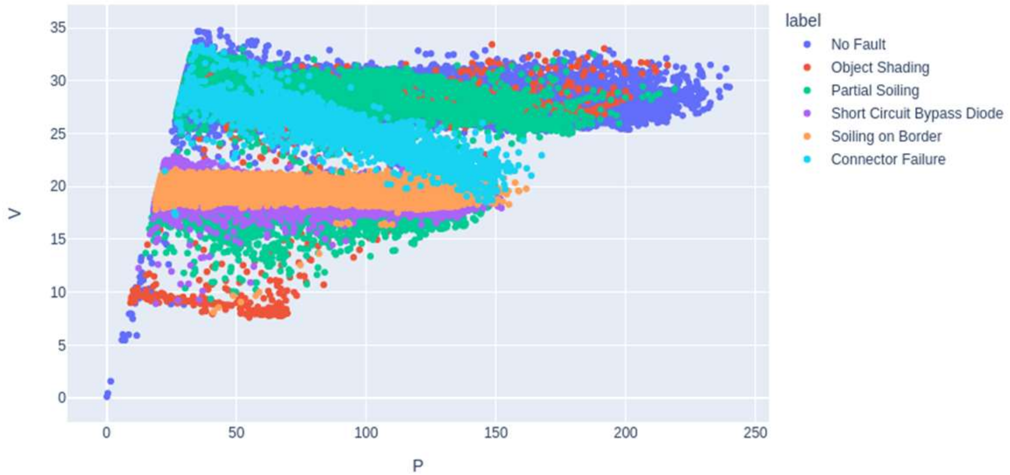


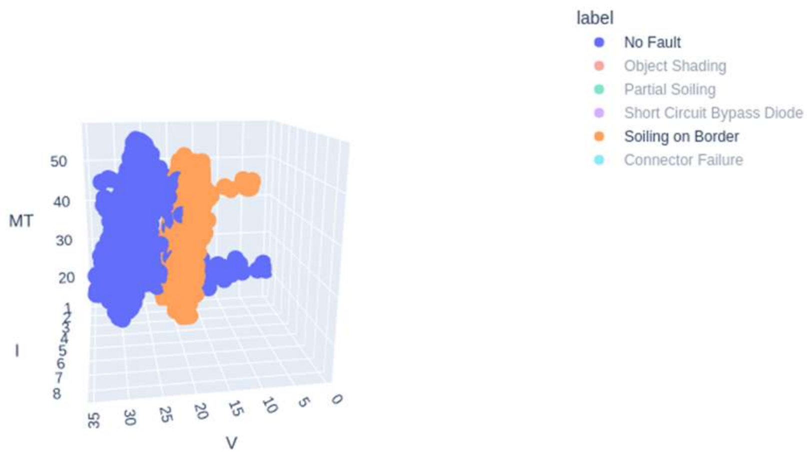
A look at the processed data

Distribution of voltage by fault



Relationship between power and voltage





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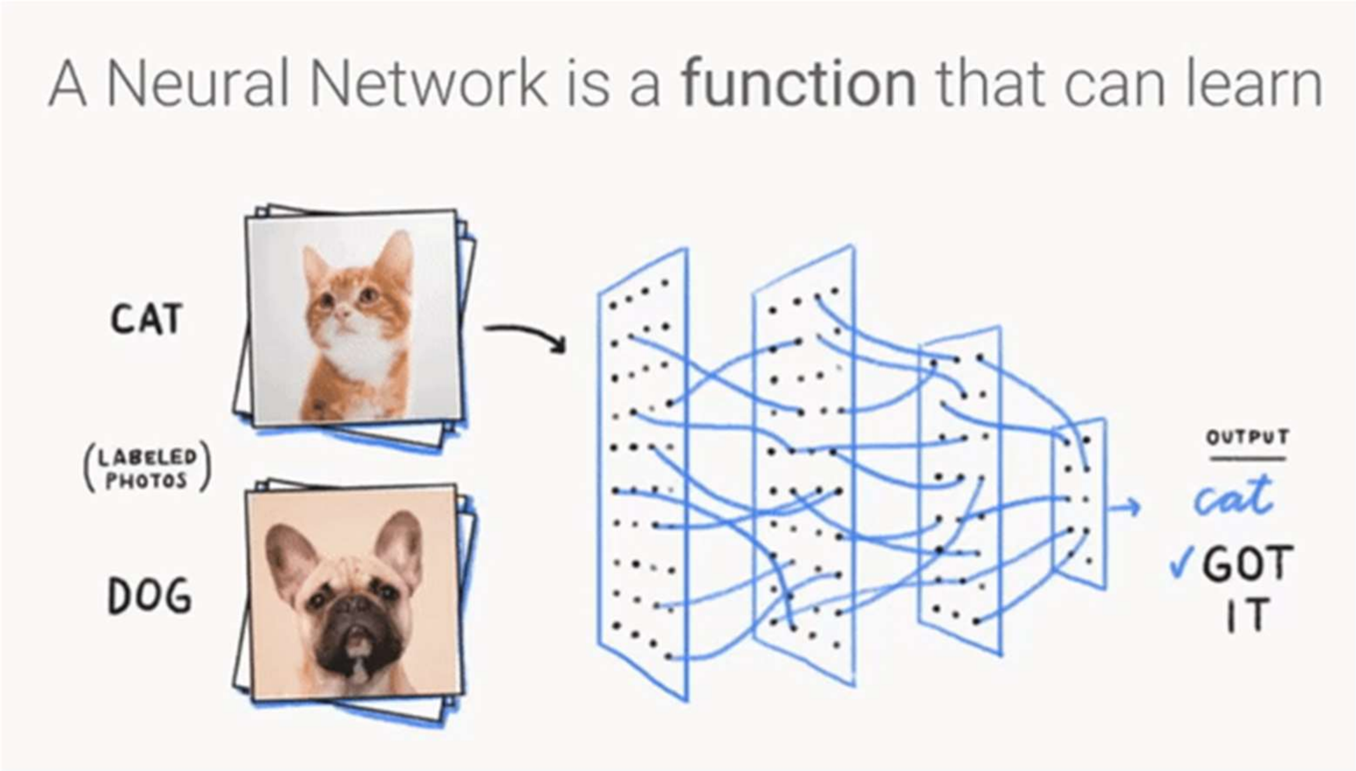
Input Features

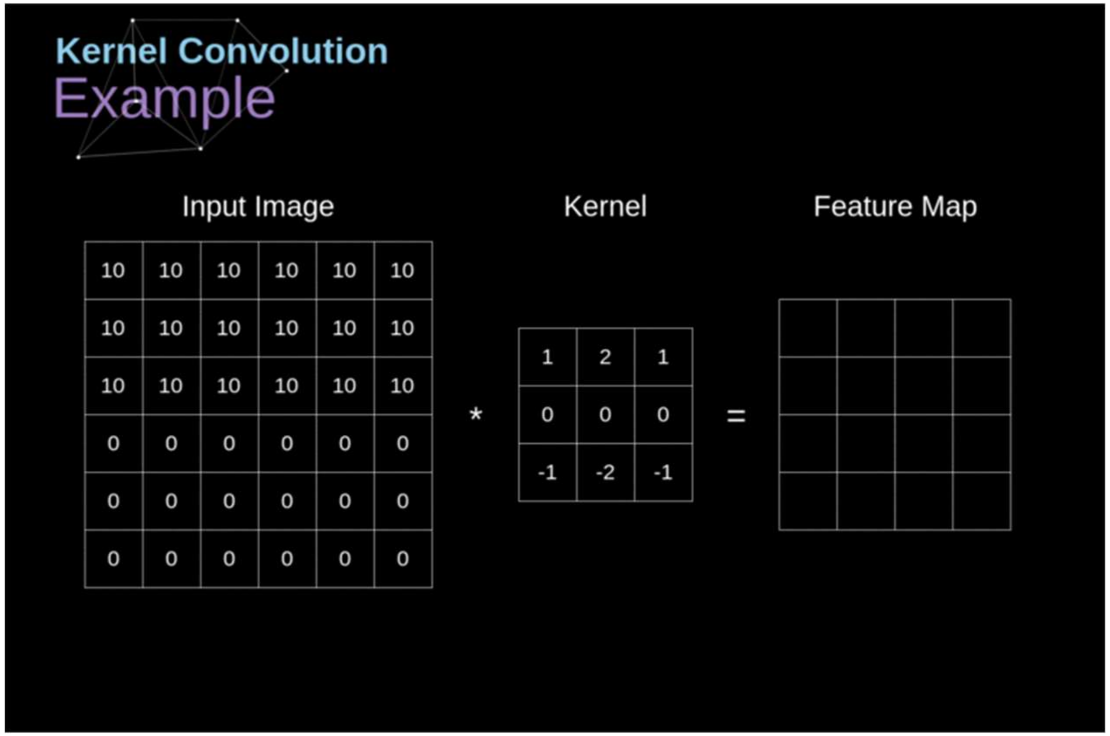
Measured Features
Voltage (V)
Current (I)
Average Global Horizontal Irradiance (G)
Module Temperature in Celsius (MT)
Computed Features
Power (P)
Expected Power (Pexp)
Expected Current (Iexp)
Expected Voltage (Vexp)
Expected Open Circuit Voltage (Voc_exp)
Expected Short Circuit Current (Isc_exp)

Ratio Features
P / Pexp
V / Vexp
I / Iexp
V / Voc_ref
I / Isc_ref
V / Voc_exp
I / Isc_exp

What is a neural network?



Convolutional Neural Networks for image classification (2D)



Source: Skalski, P. (2021, December 9).

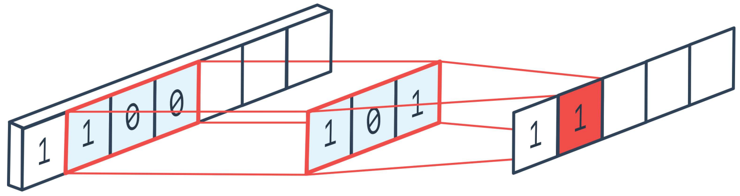
Convolutional Neural Networks for signal processing (1D)

- Neighboring points in timeseries are related, convolution exploits this!

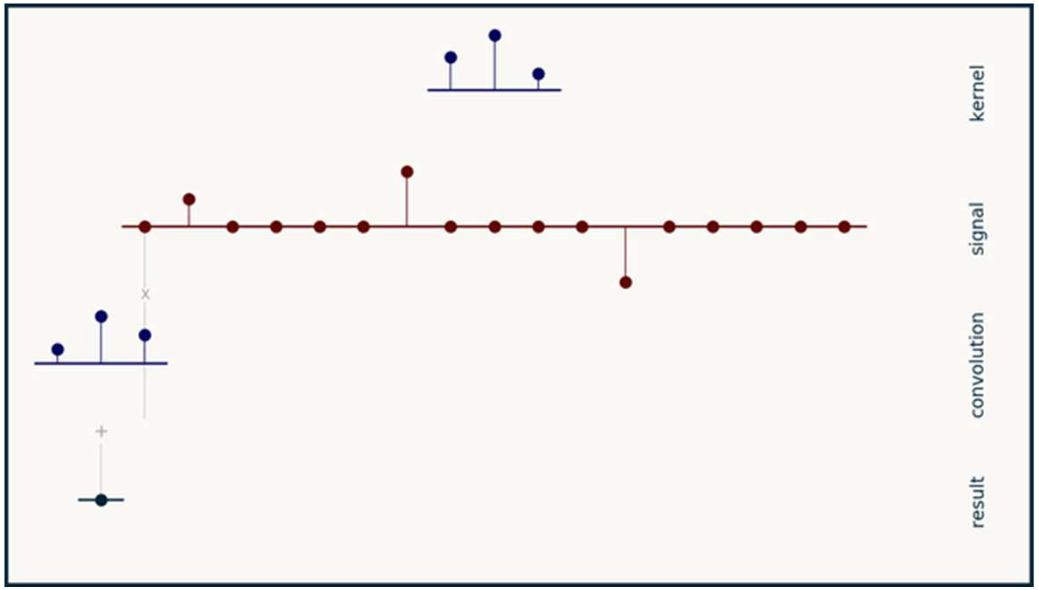
- Finds local patterns that reoccur in the data.

- Models learns different types of patterns (kernels) through backpropagation.

- Goal is to minimise model error (loss function).



Source: Peltarion, P. (2021).



Source: Rohrer, B. (2020).

Model Architectures

Single-minute observations as input
2-layer 1D CNN model with 17 features.

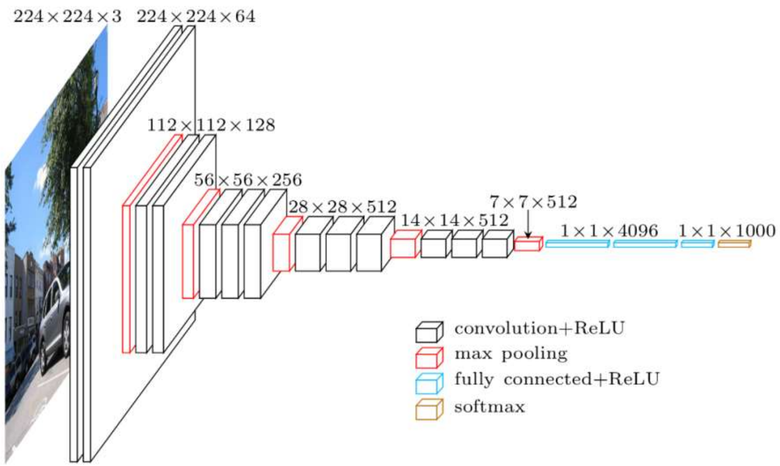
Multi-hour time window as input
6-layer 1D CNN model, with Dropout and MaxPooling inspired by VGG model with only 4 measured features (V, I, G, MT).

Prediction format
Probability distribution over classes e.g.

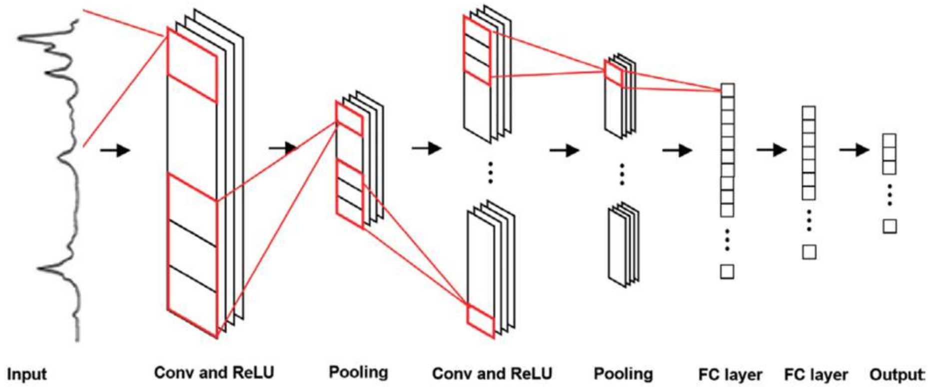
```
[0.08, 0.72, 0.11, 0.09]
[class 0, class 1, class 2, class 3]
```

Maximum probability represents class

```
[0, 1, 0, 0]
```



Source: Sugata & Yang (2017).

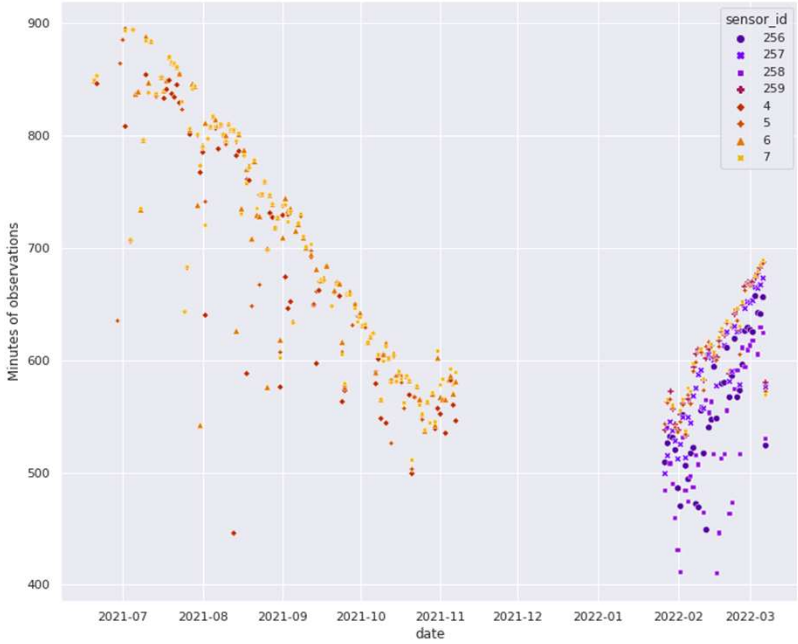


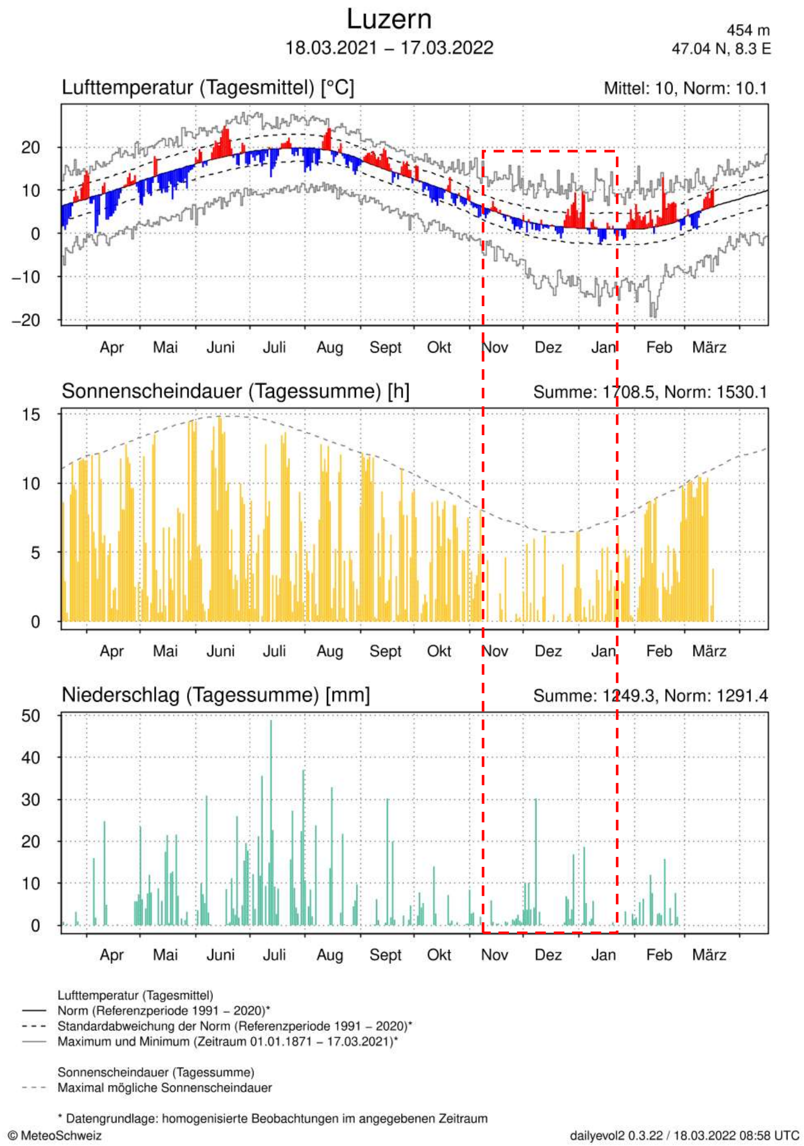
Source: Mozzafari & Tay (2020).

Model Training

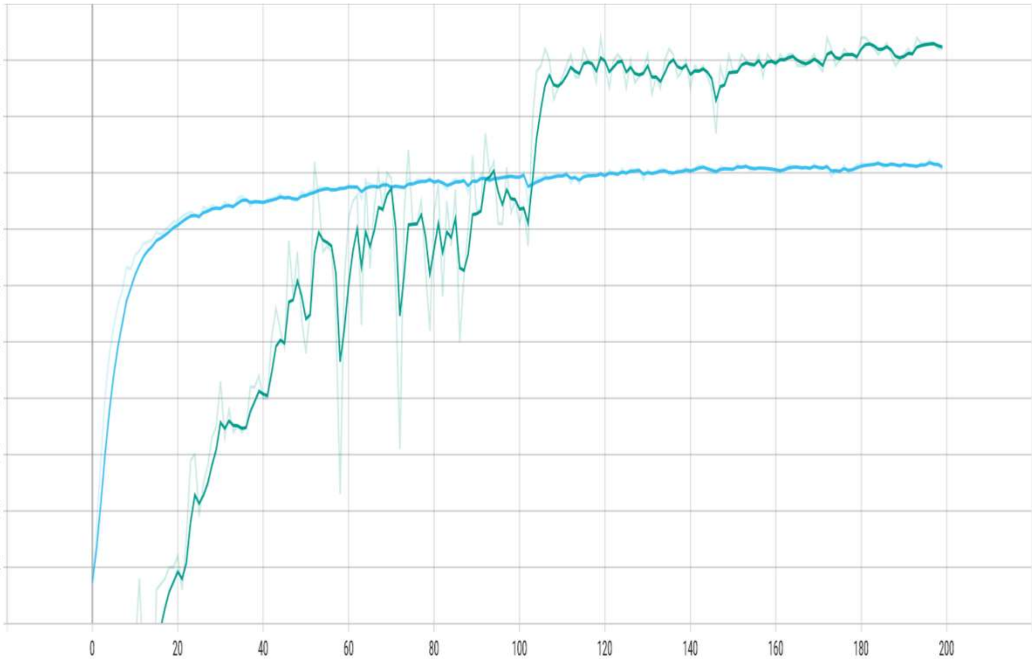
Single-minute observations as input
Data selected from May – October 2021.

Multi-hour time window as input
Data selected from May – November 2021, January – March 2022.

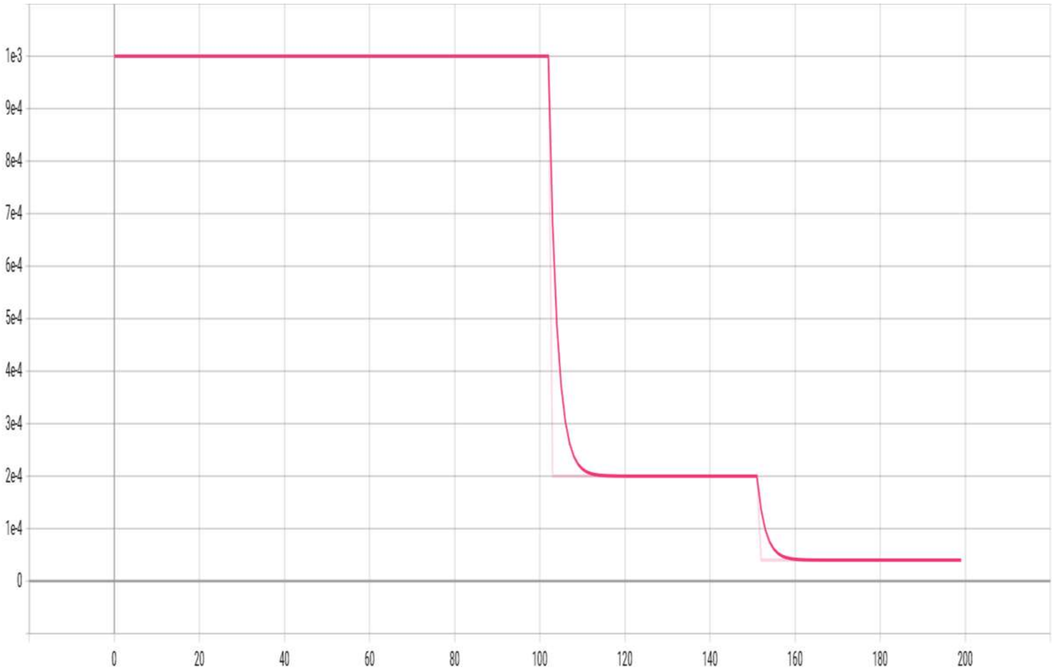




Single vs multi-timestamp training accuracy on validation set



Single-timestamp model (blue), Multi-timestamp model (green)



Learning rate reduction during detection of a plateau

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Model Evaluation Metrics

Model is evaluated on an unseen test set comprising 20% of the dataset (~82,000 min. Observations).

Evaluation metrics are computed on a per class basis.

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

$$Precision = \frac{TP}{TP + FP}$$

$$Recall = \frac{TP}{TP + FN}$$

$$F1 = 2 \cdot \frac{precision \cdot recall}{precision + recall}$$

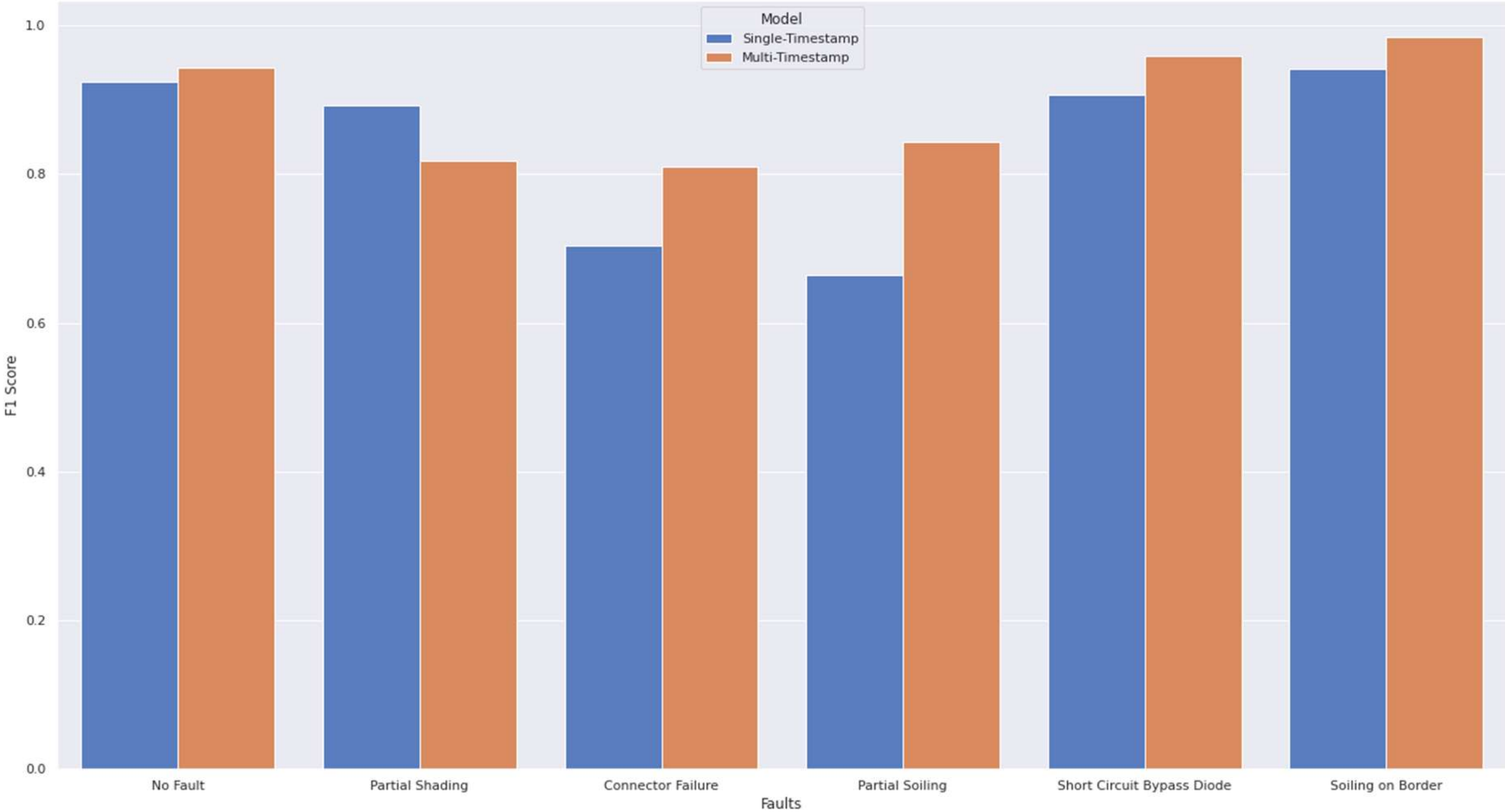
TP = True positive

TN = True negative

FP = False positive

FN = False negative

Results – F1 Score



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Full Integer quantization & deployment to TensorFlow Lite Micro

Model is converted to TensorflowLite. Represented in portable FlatBuffers file format.

FlatBuffers models are smaller in size and have a decreased latency on low resource devices.

Full Integer quantisation is applied after training. Model parameters are cast from float32 to int8 (4x size reduction).

Hexdump of FlatBuffers file is saved as a C++ array ready to be deployed on a microcontroller.

Future work

Collecting additional fault data.

Deployment & inference workflow.

Dealing with flash size limitations.

Exploration of on-device training.

References

[1] S*kalski, P. (2021, December 9). Gentle Dive into Math Behind Convolutional Neural Networks. Medium. https://towardsdatascience.com/gentle-dive-into-math-behind-convolutional-neural-networks-79a07dd44cf9*

[2] Rohrer, B. (2020, February 29). *Convolution in one dimension for neural networks*. Https://E2eml.School/. https://e2eml.school/convolution_one_d.html

[3] *1D Convolution*. (2021). Peltarion. https://peltarion.com/knowledge-center/documentation/modeling-view/build-an-ai-model/blocks/1d-convolution

[4] Sugata, T & Yang, C. (2017). Leaf App: Leaf recognition with deep convolutional neural networks. IOP Conference Series: Materials Science and Engineering. 273. 012004. 10.1088/1757-899X/273/1/012004.

[5] Mozaffari, M. H., & Tay, L.-L. (2020, June 18). *A review of 1d convolutional neural networks toward unknown Substance Identification in Portable Raman spectrometer*. arXiv.org. Retrieved March 21, 2022, from https://arxiv.org/abs/2006.10575

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Thanks!

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