Sensor, Signal and Information Processing (SenSIP) Center and Industry Consortium

Real-time Embedded Machine Learning for Solar Energy Monitoring and Control

Project Lead: PI Cihan Tepedelenlioglu

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Industry Mentors and key Collaborators Dr. Devarajan Srinivasan

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Project will address

- Development of Embedded Machine Learning methods for Real time monitoring and control of PV
- Hardware and Algorithms for PV Fault Detection
- Hardware and Algorithms for PV Topology Optimization
- Produce publications and IP in the area
- Work jointly with our members on federal proposals (e.g., SBIR, STTR)

Objectives

Develop Embedded Machine Learning Algorithms for Fault Detection

Explore and Select Embedded Controller for use in this project

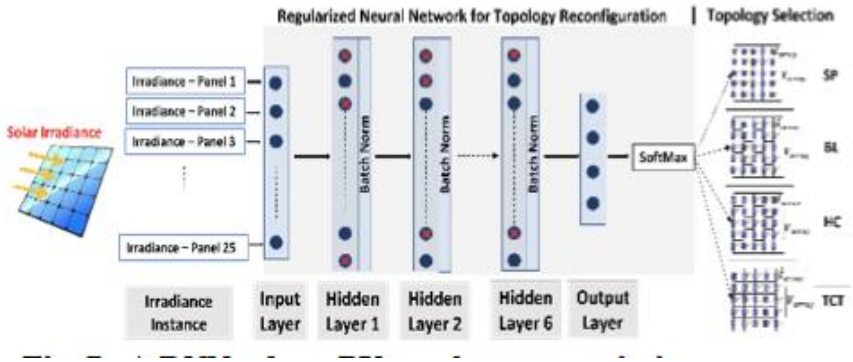
Develop Real-time Embedded ML for Fault Detection

Develop Real-time Embedded ML for Topology Optimization

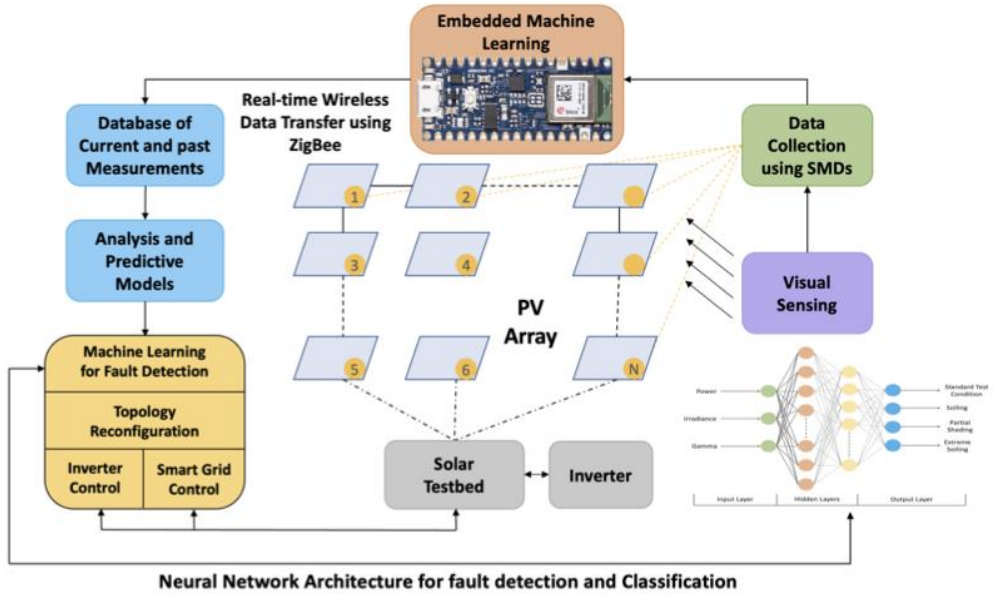
Explore Edge vs Cloud Computing implementations

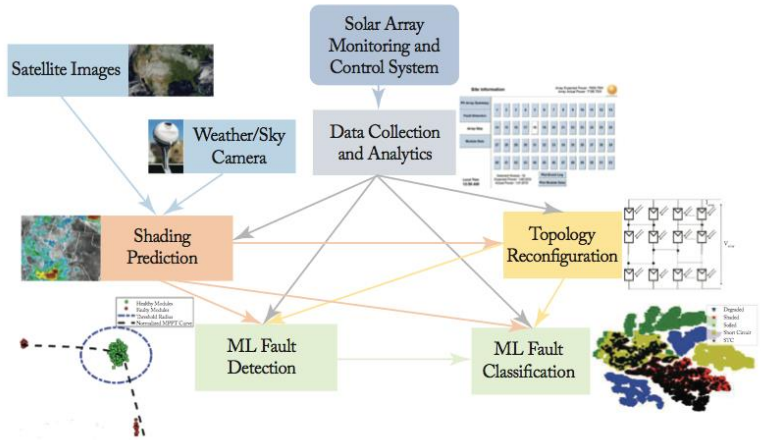
Real-time demonstration at MTW Facility

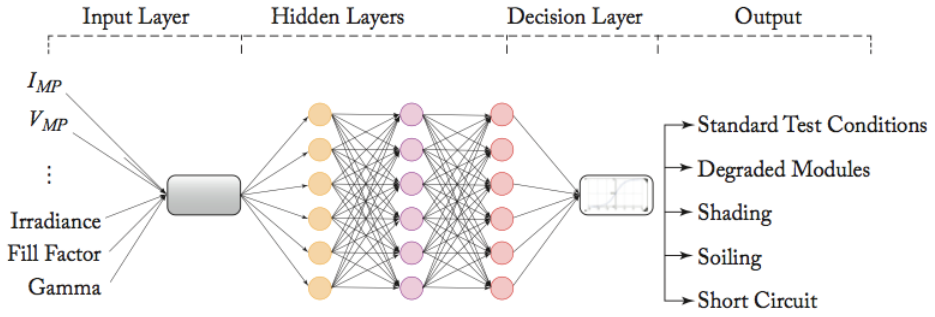
Develop reports and publications

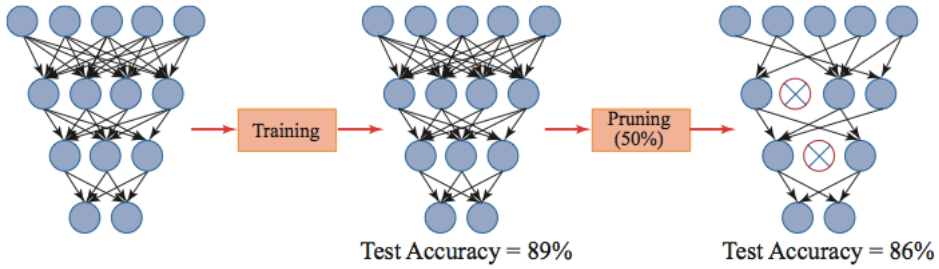


Algorithms / Visuals









Prior Work in Machine Learning for Solar Energy

PV Fault Detection using Pruned Neural Nets. Published in IEEE Access, Dec. 2022. Patent Established

PV Topology Optimization. Simulation published in IEEE Access January 2023. Provisional Patent established

Preliminary work on developing hardware to be transmitted Dec. 15, 2023 to 2024 IEEE ICPS (industry cyber physical systems)

Cloud Movement Prediction paper for PV shading applications to be transmitted to IEEE Access Dec 2023.

Problem Statement

- **What is the specific problem to be solved?**
- Creating embedded machine learning algorithms for real time PV fault detection
- Developing embedded machine learning algorithms for real time Topology Optimization
- Developing and testing hardware for our implementations.
- Evaluating all algorithms and performing real time testing

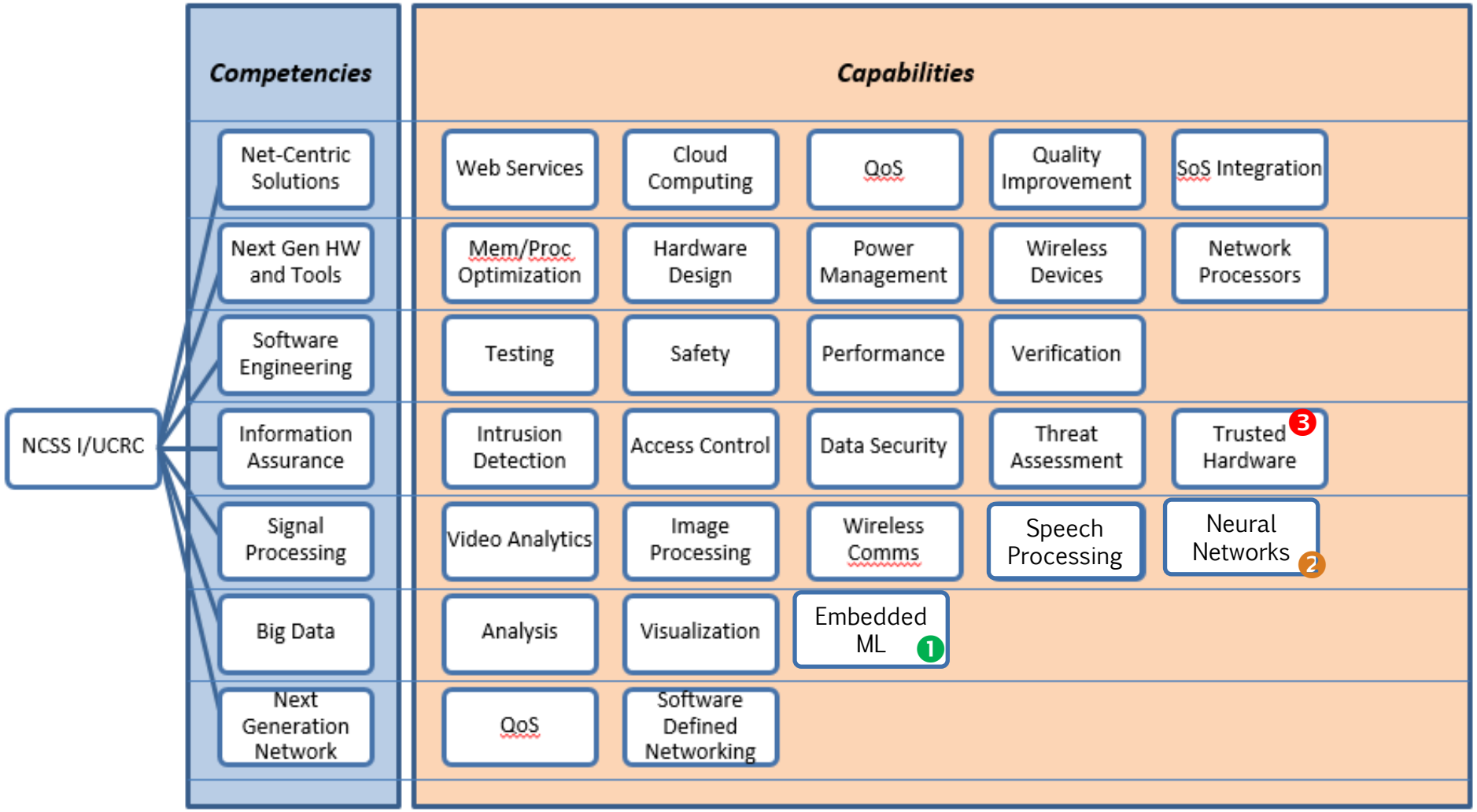
- **Why is this research needed?**
- Fault detection and topology optimization will enhance efficiency and robustness
- Embedded and pruned Neural Net research will have broader applications
- Theoretical and experimental results will potentially impact PV development standards

Project Description

- How will this project approach the problem?
  - Optimize pruning for operation on embedded controller platform
  - Create at least three PV topologies and test the algorithms real time
  - Combine Edge and Cloud computing for fault detection
  - Examine possibilities for implementing on parallel GPUs

- Preliminary results from this or previous projects:
  - Results on Fault Detection published in 2021
  - Results on topology optimization showed promise for more than 10% elevated power
  - Imaging aspects for shading prediction have been established.
  - Some of the hardware was developed for simple PV fault detection cases (IEEE IISA 2023)

Connection to Center Competencies/Capabilities



1=Primary, 2=Secondary, 3=Tertiary

Statement of Work

Work to be performed, timeline and tasks. 2 year project

Briefly describe the work to be performed, task budgets, and deliverables for the 5 most important tasks planned for this project.

Task#	*Description*	*Budget*	*Deliverable*
Task-1 Y1	Examine Pruned NN	3 MOS	Algorithm, Report, Software
Task-2 Y1	Hardware Development	3 MOS	Hardware, Report, Software
Task-3 Y1	Apply to Fault Detection	2 MOS	Report, Software
Task-4 Y1	Research on Topology Optimization	2 MOS	Report, Software
Task-5 Y1	Finalize Results Prepare Publication and Report	2 MOS	Publication, Report Y1
YEAR 2	Real time implementation, Integration, Testing at MTW Details on Tasks in next meeting	12 MOS	Research, Software and Publication Testing and performance evaluations

Project Differentiators

- What results does this project seek that are different (better) than others?
  - Real-time Embedded ML for Fault detection
  - Real-time Embedded ML for Topology Optimization
  - Integration and Real time testing of PV Hardware and Software
- What specific innovations or insights are sought by this research that distinguish it from related work?
  - Novel Embedded Pruned and Parallel NNs
  - Unique real time hardware for PV applications
  - Extensions to other sensor areas

Potential Member Company Benefits and Sponsorship and Collaboration

This research is expected to benefit several members of SenSIP

Examples Include:

- Poundra
- Prime Solutions Group (PSG)
- NXP (microcontrollers)

References

[1] S. Rao, G. Muniraju, C. Tepedelenlioglu, D. Srinivasan, G. Tamizhmani and A. Spanias, "Dropout and Pruned Neural Networks for Fault Classification in Photovoltaic Arrays, pp. 120034-120042, *IEEE Access*, 2021

[2] Systems and methods for skyline prediction for cyber-physical photovoltaic array control – Part B, S. Katoch, P. Turaga, A. Spanias, C. Tepedelenlioglu, US Patent 11,694,431 Part B, Issued July 2023.

[3] M19-149P Systems and Methods For Connection Topology Optimization In Photovoltaic Arrays Using Neural Networks, V. Narayanaswamy, A. Spanias, R. Ayyanar, C. Tepedelenlioglu, US Patent 11,616,471, March 2023.

[4] S. Rao, A. Spanias, C .Tepedelenlioglu, (M19-102P) , Solar Array Fault Detection, Classification and Localization Using Deep Neural Nets, US 11,621,668, April 2023.

[5] V. Narayanaswami, R. Ayyanar, A. Spanias, C. Tepedelenlioglu, "Reconfiguring Photovoltaic Arrays for Maximum Power Output Extraction using Neural Networks," *IEEE Access, January 2023*

[6] S. Rao, S. Katoch, V. Narayanaswamy, G. Muniraju, C. Tepedelenlioglu, A. Spanias, P. Turaga, R. Ayyanar, and D.Srinivasan, "Machine Learning for Solar Array Monitoring, Optimization, and Control," Synthesis Lectures on Power Electronics, Morgan & Claypool, Ed. J. Hudgins, Book, 91 pages, ISBN: 9781681739076, Aug. 2020.