NDnano
Notre Dame Nanoscience and Technology

NDnano Summer Undergraduate Research
2023 Project Summary

1. Student name & home university: James Boumalhab, University of Notre Dame

2. ND faculty name & department: Professor Yih-Fang Huang, Professor Ningyuan Cao, Department of Electrical Engineering

3. Summer project title: Adaptive federated learning for sustainable, secured, and robust distributed intelligence: Algorithm and hardware co-design

4. Briefly describe new skills you acquired during your summer research:

During the summer, I attained a diverse array of skills in the realm of machine learning, including implementing various algorithms such as multiple linear regression, adaptive filtering, and artificial neural networks, not just to understand them conceptually but also to enhance and optimize their performance for data processing. In addition, I learned how to effectively present my findings and discuss the importance of my research.

5. Briefly share a practical application/end use of your research:

In many environments, things do not change as rapidly as the data samples are received. Thus, continuous updates of parameters in adaptive filters within sensor systems become unnecessary. The employment of adaptive filtering algorithms, like the set-membership normalized least mean square (SM-NLMS) algorithm, becomes valuable in such cases. By incorporating an innovation check, the algorithm selectively triggers updates of parameters only when deviations from normal environmental behaviors are detected. This approach conserves resources, making the sensor system more adaptable and efficient, especially in stable environments. Thus, the use of such algorithms further enhances the optimization of data processing in network sensor systems.

6. 50- to 75-word abstract of your project:

Sensors play a crucial role in collecting and transmitting data from the environment. However, they can go beyond data collection, e.g., sensor nodes can process data. To make data processing more efficient, the SM-NLMS adaptive filtering algorithm is employed to reduce unnecessary updates of filter parameters. Through MATLAB simulations, we observed up to 35% fewer updates with the innovation check. The algorithm showed fast convergence and improved data processing efficiency. Our research emphasizes the benefits of adaptive filtering with an innovation check, optimizing sensor networks.

7. References for papers, posters, or presentations of your research:

[1] K. Chen, S. Werner, & Y. F. Huang, “Selective Diffusion Scheme for Distributed Intelligence”

[2] R. Dastres & M. Soori, "Artificial Neural Network Systems." International Journal of Imaging and Robotics, vol. 21, 2021, pp. 13-25

[3] N. Ketkar, "Stochastic Gradient Descent," 10.1007/978-1-4842-2766-4_8, 2017

[4,5] S. Haykin, "Adaptive Filter Theory", Pearson, 2014

One-page project summary that describes problem, project goal and your activities / results:

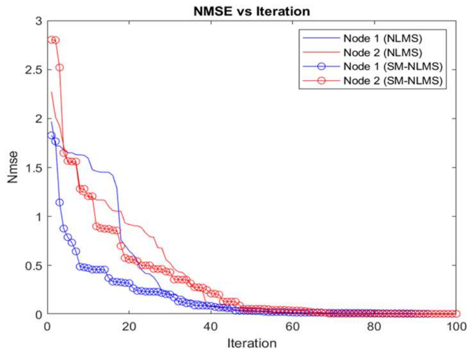
Sensors are found everywhere around us, ranging from environmental monitoring systems to agricultural systems. They play a vital role in data collection, processing, and transmission. However, in many applications, continual data processing is unnecessary. Thus, our project's ultimate goal is to enhance and integrate conventional adaptive filtering algorithms into sensor systems.

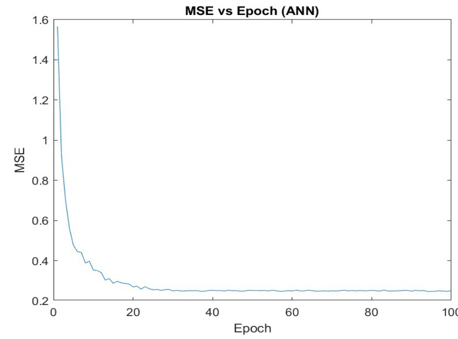
Adaptive filtering algorithms, like Least Mean Squared (LMS) and Recursive Least Squared (RLS), are widely used in machine learning to optimize parameters based on input data. Although valuable, their constant parameter adjustments, often unnecessary, pose a limitation. To address this, we introduced the Set-Membership Normalized Mean Squared (SM-NLMS) algorithm, which incorporates an innovative check. This unique feature detects deviations from normal environmental behaviors, triggering updates only when necessary. The algorithm adjusts the adaptive filter's parameters if the error check, the difference between actual and predicted output, exceeds a pre-set bound; otherwise, no adjustments are made. To evaluate our approach, we created simulated sensor scenarios with random data, parameters, and noise, replicating real measurements. The algorithm was iteratively applied over a fixed number of iterations, calculating error values between artificial data and predicted output, and then adjusting parameters accordingly. For further exploration, we considered an alternative approach, implementing an artificial neural network (ANN) for data processing, making use of its ability to deal with non-linearity. The ANN underwent training using the backpropagation algorithm [2] and stochastic gradient descent [3] optimization, and the evaluation was done using real estate and breast cancer datasets. Additionally, we integrated the innovation check into the backpropagation algorithm to further enhance the ANN's efficiency.

To evaluate those algorithms, we utilized the Mean Squared Error (MSE) and Normalized Mean Squared Error (NMSE) metrics, measuring convergence during the learning process. By simulating 2 nodes out of a 5-node network using both NLMS and SM-NLMS, we endeavored to find the best parameters that make SM-NLMS comparable to NLMS. The evaluations yielded promising results. The NMSE approached zero, and nodes using the SM-NLMS algorithm displayed a remarkable improvement on data usage – specifically, it uses 35% less data to achieve the same performance as NLMS does. Moreover, the ANN exhibited an impressive efficiency boost of approximately 71%. These findings suggest that employing the SM-NLMS algorithm with an innovation check and utilizing artificial neural networks can significantly enhance overall performance and efficiency in data processing for sensor networks.

Figure 1: Normalized Mean Squared Error convergence as NLMS and SM-NLMS simulated on 2 nodes

Figure 2: Mean Squared Error convergence as back propagation algorithm learns


NMSE vs Iteration
Node 1 (NLMS)
Node 2 (NLMS)
Node 1 (SM-NLMS)
Node 2 (SM-NLMS)
Nmse
Iteration


MSE vs Epoch (ANN)
MSE
Epoch