

Development of a PINN-Based AI Algorithm for Inventory Verification of CANDU Spent Nuclear Fuel

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Korea Institute of Nuclear non-proliferation And Control (KINAC) has developed the Improved Optical fiber-based Verification System (IOVES) and applies it to physical inventory verification (PIV) of nuclear fuel bundles in the wet storage facility for spent nuclear fuel at the Wolsong CANDU reactor. IOVES scans between spent fuel bundles at a constant speed using a scintillator-attached optical-fiber probe and constructs a radiation profile depending on measurement depth to identify gross defect of spent nuclear fuel bundles. Although radiation signals depending on the measurement depth can be clearly observed from the radiation profile, it is difficult to individually discriminate the contributions from the left and right bundles. Because IOVES detects incoming radiation without separating the signals from either side. To overcome this hardware limitation of IOVES, this study developed a deep-learning-based spent nuclear fuel bundle verification algorithm.

In this study, physics-informed neural network (PINN) was employed as a deep-learning model. The PINN model includes physical relationships in the loss function so that the model learns predictions that are consistent with fundamental physical principles.

For the dataset construction, radioactivity of Cs-137 from a total of 2,280 CANDU spent fuel bundles was utilized. Each single data sample consists of a randomly selected combination of 38 bundles and includes the bundle arrangement and activities (19×2 , A) and the radiation profile (322×1 , P) as inputs and the missing-bundle labels for each bundle (19×2 , S) as output.

The model outputs the predicted missing status of each bundle (S_{pred}) and the predicted radiation profile (P_{pred}), and training is iterated until the mean squared error between the ground truth and two outputs is minimized.

The prediction performance of the proposed model achieved an accuracy of 0.9975, precision of 0.9990, recall of 0.9985, specificity of 0.9572, and an F1-score of 0.9987.

In future work, we will improve the algorithm through visual analysis of the ground truth and predicted profiles. And we will validate field applicability by applying radiation profiles measured in the wet storage pool as test data.

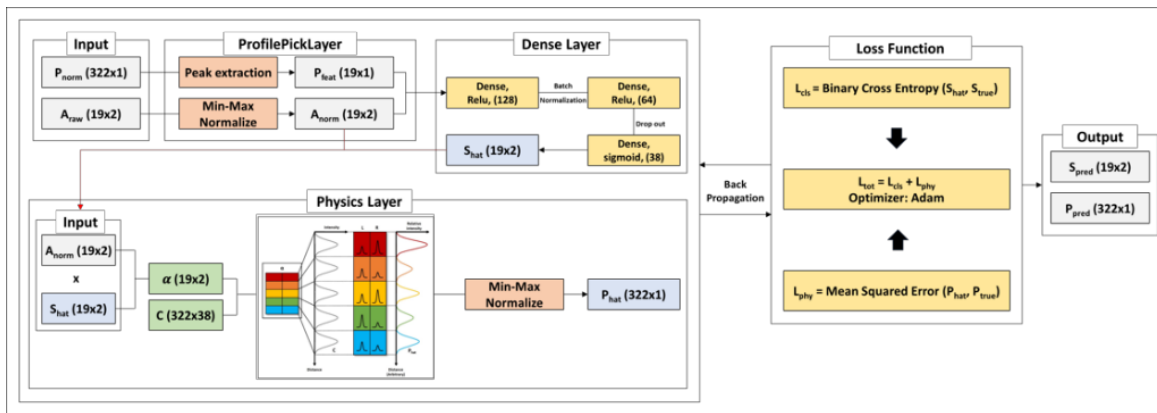


Figure 1. Schematics of PINN based Spent Nuclear Fuel Bundle Verification Algorithm

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