Reconstruction of pile-up events using an Autoencoder based on CNN for the NEDA detector array

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***Abstract*—Pulse pile-up poses an issue in the study of nuclear reactions and spectroscopy, arising when two pulses overlap, distorting data and compromising the accuracy of energy and timing details. Various digital and analogue techniques have been used to deal with pile-up interference. However, some pile-up events may include interesting pulses that require reconstruction. This study introduces a novel approach to reconstructing pile-up events acquired using the Neutron Detector Array (NEDA), employing an Autoencoder based on a Convolutional Neural Network (CNN). The training and testing datasets for the Autoencoder have been created from NEDA data. This new pile-up signal reconstruction method has been evaluated considering the similarity between reconstructed signals and the originals. Furthermore, it has been analysed from the point of view of Charge Comparison (C.C.), comparing the result obtained from original and reconstructed signals.**

***Index Terms*—Neutron detector, Neutron-Gamma Discrimination, Pulse Shape Analysis, Charge Comparison, Autoencoder, Convolutional Neural Network**

I. INTRODUCTION

Pulse pile-up frequently occurs in nuclear spectroscopy experiments and high-count-rate nuclear reaction studies. This phenomenon arises when pulses arrive closely in time, leading to total or partial overlap. As depicted in Fig. 1, this overlap distorts the two pulses, deteriorating the precision of energy and timing data. Consequently, it becomes challenging to discern particle types through pulse shape discrimination techniques [1]. As a result, these events are typically discarded and left unanalysed.

To address this, various rejection techniques exist [2], [3], ranging from digital methods like leading-edge discrimination to analogue approaches like pulse-shape fitting. However, these techniques discard events that might contain valuable information, prompting efforts to recover lost data from pile-up occurrences.

Some methods focus on refining distorted pulse height spectra, while others aim to treat signals individually [4]–[8]. In the case of NEDA, it is necessary to treat the signals individually to include them in the analysis chain later. For this purpose, it has been proposed to use a machine learning technique: an Autoencoder structure based on 1D-CNN. With this technique, the objective is to disentangle and reconstruct the two pulses within each pile-up event. In order to apply this technique, the NEDA signals have been studied in detail and NEDA detector data have been used to train the model. The resulting signals have been analysed after passing pile-up signals through the Autoencoder structure based on 1D-CNN.

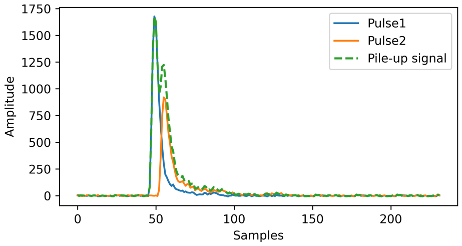

Fig. 1. Example of a signal with pulse pile-up efect.

II. DATA ACQUISITION AND DATASET GENERATION FROM NEDA

Data have been acquired during on-beam experiments conducted at the Heavy Ion Laboratory (HIL, Poland) to generate the data necessary for training and testing. Signals from the NEDA detectors have been recorded independently by a Caen V1725SB digitiser (250 MHz, 14-bit). Subsequently, the acquired signals have been analysed to generate pile-up events artificially.

NEDA exhibits sensitivity to neutrons and γ-rays. So, Neutron Gamma Discrimination (NGD) is essential to determine the radiation's type. The C.C. combined with Time-of-flight is the technique used for NGD in NEDA [9]. The C.C. method uses the ratio of the integral from two different time windows of the signal waveform to distinguish between neutrons and γ-rays. If the ratio exceeds a certain threshold (0.525 in this experiment), the signal is considered a neutron; if the ratio is lower than the threshold, it is a gamma ray.

Once the signals have been analysed and classified, only γ-n and n-γ combinations have been created since, due to the characteristics of the detector and the type of particles, only these combinations can happen. So, the dataset created is focused exclusively on γ-n or n-γ pile-up events. The pile-up event is created by taking the digital samples of one signal of each type, delaying one by a variable amount of samples and them adding both creating pile-up signals of which the original signals are perfectly known. These signals have been used for training and the original ones are used as ground truth to carry out the training of the Autoencoder.

III. RECONSTRUCTION OF PILE-UP PULSES USING CNN-BASED AUTOENCODER

The Autoencoder machine learning architecture is a design typically used for denoising and image reconstruction (2 Dimensions).

For this case, the same type of architecture has been used but, in this case, applied to a time series (1 Dimension), separating and reconstructing pile-up signals. Fig. 2 shows the architecture used.

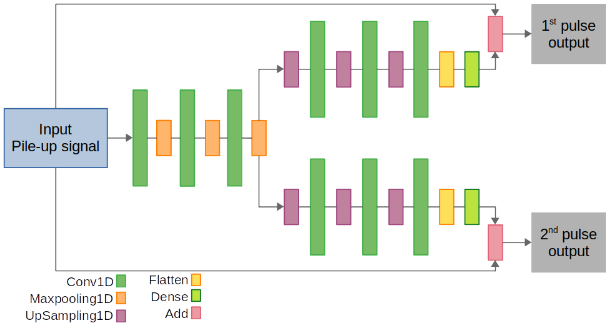

Fig. 2. CNN-based Autoencoder architecture.

A. Analysis of reconstructed signals for NEDA

After training the Autoencoder model, it has been tested with unknown signals, and the reconstructed signals were evaluated by comparing them with the original signals. The evaluation considered the distance between pulse peaks and the possible combinations (γ-neutron and neutron-γ). A new dataset of 5000 events for each peak-to-peak distance has been generated.

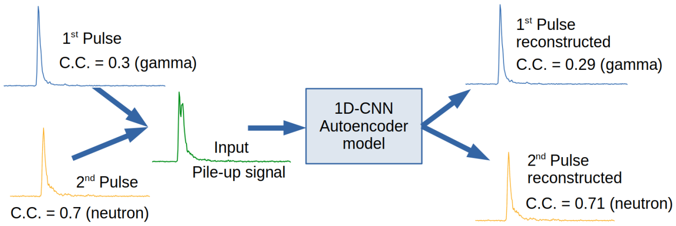

Fig. 3. Example of pile-up reconstruction.

The correlation has been used to assess the similarity between the reconstructed and original signals before the pile-up, with 1 indicating perfect correlation, 0 no correlation, and -1 inverse correlation. The mean correlation obtained has been 0.988. Fig. 4 shows the average correlation for each combination and each distance between pulses.

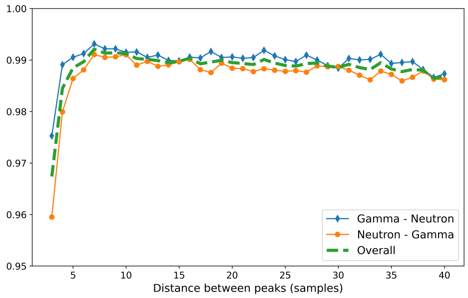

Fig. 4. Average correlation per delay.

On the other hand, the analysis aimed at verifying that the expected type of event (neutron or gamma) is obtained after reconstructing a pile-up event. For this, the reconstructed signal has been analysed using C.C. and compared with the value of C.C. calculated with the original signal.

Afterwards, the results have been analysed focusing on the accuracy in determining whether it is a neutron or a gamma. In total, 85.53% of the events are correctly identified. Fig. 5 shows the percentage of success for each combination and each distance between pulses.

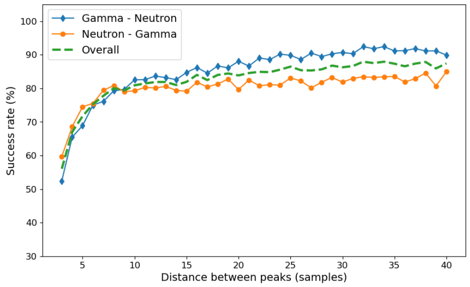

Fig. 5. Percentage of success by distance between peaks.

IV. CONCLUSIONS

To sum up, the study tackled the challenge of pulse pile-up in nuclear spectroscopy by proposing the use of a 1D-CNN-based Autoencoder to disentangle and reconstruct overlapped signals. Results showcased a high similarity between the original and reconstructed signals, with an average correlation of 0.988, and 85.53% success in identifying particles post-reconstruction. This technique holds promise in mitigating adverse effects of pulse pile-up, salvaging previously discarded valuable information, and empowering future high-count-rate nuclear reaction and nuclear spectroscopy studies.

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