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Machine Learning for Real-Time Processing of ATLAS Liquid Argon Calorimeter Signals with FPGAs

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The ATLAS experiment at the Large Hadron Collider (LHC) is operated at CERN and measures proton-proton collisions at multi-TeV energies with a repetition frequency of 40 MHz. Within the phase-II upgrade of the LHC, the readout electronics of the liquid-argon (LAr) calorimeters of ATLAS are being prepared for high luminosity operation expecting a pileup of up to 200 simultaneous proton-proton interactions. Moreover, the calorimeter signals of up to 25 subsequent collisions are overlapping, which increases the difficulty of energy reconstruction by the calorimeter detector. Real-time processing of digitized pulses sampled at 40 MHz is performed using field-programmable gate arrays (FPGAs).
To cope with the signal pileup, new machine learning approaches are explored: convolutional and recurrent neural networks outperform the optimal signal filter currently used, both in assignment of the reconstructed energy to the correct proton bunch crossing and in energy resolution. The improvements concern in particular energies derived from overlapping pulses.
Since the implementation of the neural networks targets an FPGA, the number of parameters and the mathematical operations need to be well controlled. The trained neural network structures are converted into FPGA firmware using automated implementations in hardware description language and high-level synthesis tools.
Very good agreement between neural network implementations in FPGA and software based calculations is observed. The prototype implementations on an Intel Stratix 10 FPGA reach maximum operation frequencies of 344–
640 MHz. Applying time-division multiplexing allows the processing of 390–576 calorimeter channels by one FPGA for the most resource-efficient networks. Moreover, the latency achieved is about 200 ns. These performance parameters show that a neural-network based energy reconstruction can be considered for the processing of the ATLAS LAr calorimeter signals during the high-luminosity phase of the LHC.

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