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Accelerating Detector Alignment Calibration with Real-Time Machine Learning on Versal ACAP Devices

Modern beam telescopes play a crucial role in high-energy physics experiments to precisely track particle interactions. Accurate alignment of detector elements in real-time is essential to maintain the integrity of reconstructed particle trajectories, especially in high-rate environments like the ATLAS experiment at the Large Hadron Collider (LHC). Any misalignment in the detector geometry can introduce systematic biases and potentially affect the accuracy of precision physics measurements. Current calibration systems that correct for these effects require substantial computational resources and these methods often lead to high operational costs and are often unable to handle rapidly changing conditions, leading to systematic inaccuracies and potential biases in physics measurements.

To address these challenges, we propose a calibration system that employs a lightweight neural network to predict the misalignment of the detectors in real time. Our approach utilizes multilayer perceptron (MLP) with hierarchical subset solver for deployment on heterogeneous computing platforms. The neural network predicts detector misalignments based on the detectors current positional data and statistical characteristics of particle trajectories.

This approach leverages ML to predict control parameters in real-time, allowing adaptation to complex nonlinear behaviors. However, this introduces a significant computational workload, as the optimization process involves frequent and dense matrix multiplications for gradient-based updates, which makes efficient hardware acceleration essential. By partitioning the application based on its computational characteristics: leveraging CPUs for sequential tasks, FPGAs for parallel workloads, and AI engine cores for fast and energy-efficient compute, we can achieve a balance of performance and cost. Deploying the algorithm on a heterogeneous computing device that leverages state-of-the-art ML-focused silicon processors could achieve cost-efficient implementation of real-time detector geometry calibration with real-time latency. This work is a step towards AI-driven real-time compute for future high-energy physics experiments on a Versal ACAP architecture, offering significant improvements in computational speed, resource utilization, and cost per watt.

Significance

References

Experiment context, if any

ATLAS, but can be relevent to any tracking systems in high-energy physics.

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