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L1 Track Finding for a Time Multiplexed Trigger

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Abstract

At the HL-LHC, proton bunches will cross each other every 25 ns, producing an average of 140 p p-collisions per bunch crossing. To operate in such an environment, the CMS experiment will need a L1 hardware trigger able to identify interesting events within a latency of 12.5 us. The future L1 trigger will make use also of data coming from the silicon tracker to control the trigger rate. The architecture that will be used in future to process tracker data is still under discussion. One interesting proposal makes use of the Time Multiplexed Trigger concept, already implemented in the CMS calorimeter trigger for the Phase I trigger upgrade. The proposed track finding algorithm is based on the Hough Transform method. The algorithm has been tested using simulated pp-collision data. Results show a very good tracking efficiency. The algorithm will be demonstrated in hardware in the coming months using the MP7, which is a uTCA board with a powerful FPGA capable of handling data rates approaching 1 Tb/s.

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L1 Track Finding for a Time Multiplexed Trigger

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Abstract

At the HL-LHC, proton bunches will cross each other every 25 ns, producing an average of 140 pp-collisions per bunch crossing. To operate in such an environment, the CMS experiment will need a L1 hardware trigger able to identify interesting events within a latency of 12.5 µs. The future L1 trigger will make use also of data coming from the silicon tracker to control the trigger rate. The architecture that will be used in future to process tracker data is still under discussion. One interesting proposal makes use of the Time Multiplexed Trigger concept, already implemented in the CMS calorimeter trigger for the Phase I trigger upgrade. The proposed track finding algorithm is based on the Hough Transform method. The algorithm has been tested using simulated pp-collision data. Results show a very good tracking efficiency. The algorithm will be demonstrated in hardware in the coming months using the MP7, which is a µTCA board with a powerful FPGA capable of handling data rates approaching 1 Tb/s.

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1. Introduction

The High Luminosity (HL-LHC) upgrade to the Large Hadron Collider will deliver an integrated luminosity of 3000 fb^{-1} to be collected in the decade following 2023. At the HL-LHC proton bunches will cross every 25 ns, producing up to 200 collisions per bunch crossing (BX) [1].

To operate in such an environment the CMS experiment needs to be upgraded (CMS Phase II Upgrade) [2]. After the LHC run III the detector will have suffered significant radiation damage, therefore many parts will be completely replaced, in particular the tracker. The new tracker will have an increased granularity in both pixel and outer tracker system, in order to maintain the same reconstruction performance. The outer system will adopt new double sensor modules, capable of rejecting signals from particles with a p_{T} lower than 2 GeV/c, considering correlation between hits in sensors of same modules consistent with a high-p_{T} track (*stub*).

Another important upgrade will involve the L1 trigger system. For the first time data coming from the Tracker will be used in the L1 trigger of a high luminosity hadron experiment. The architecture that will be used to handle the tracker data is still under discussion. An intriguing proposal is to use a Time Multiplexed system similar to the one already adopted by the Phase I Calorimeter trigger [3].

2. The Time Multiplexed Trigger

In a Time Multiplexed Trigger (TMT) all data from a single event flow through a single data processing module for assembly and processing. This requires two processing layers with a passive switching network between them, the Pre-Processor (PP) and the Main-Processor (MP). The PPs take data directly from the front-end modules, organise and format them, before distributing into the MPs. Each MP receives data from many PPs (ideally from all) that belong to a single event. Data from the next event flow to a second MP, out of phase by one LHC clock cycle. The system will have a time multiplexed period of 24 BX, therefore each MP has 24 BX to run the algorithm. In this way boundaries and sharing between processors are avoided and the synchronisation is required just within a single node.

Since this type of architecture fits naturally within an FPGA circuit, a conceptual architecture has been defined using the best hardware readily available, which is the µTCA board MP7 [4]. This card has been designed for the CMS L1 calorimeter trigger upgrade and mounts a Virtex 7 FPGA with 72 I/O links, which each operate up to 12.5 Gbps.

Logic capacity limits on last-generation FPGAs requires the tracker to be divided into 5 trigger regions in pseudo-rapidity of similar size ($\Delta\eta \sim 1.0$). Therefore data from each event will be processed in 5 MP boards.

PPs sort data before sending them to the MPs in order to reduce latency and simplify the algorithm. Analysis performed by our group shows that ordering stub data according to the estimated production angle β sensibly reduces the amount of transmitted information. To build track candidates an approach based on the Hough transform has been proposed.

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3. The L1 Track Finding Algorithm

Around 3600 stubs per event will arrive at each MP. Sorting them in order of β in segment of ~ 0.2 rad, the algorithm will operate just with an average of ~120 stubs, with a maximum of 200 at a time. The goal of the track trigger is to build L1 tracks from stub data.

The Hough transform is a method widely used in High-energy physics, as well as in other areas. The simplest version of the Hough transform permits detection of straight lines [5]. In the real space a line is defined as a set of points (x, y), while the Hough transform represents a line in terms of the slope-intercept parameters (m, q). In this way a point in the real space transforms as a line in the parameters space, while a straight line will be represented as a point.

In the first stage of the algorithm the Hough transform is applied to the stub coordinates (r, ϕ), which have the best resolution in CMS. Charged particles are of course bended by the CMS magnetic field, however they can be assumed as straight tracks to good approximation, for high-p_T particles ($p_T > 3$ GeV/c) originating from the beam-line.

$$\phi = \frac{\pm cB}{2p_T} r + \beta, \tag{1}$$

where the sign depends on the particle charge. Here the slope parameter $m = \pm cB/2p_T$ is bounded by the lower p_T limit of 3 GeV/c, while the intercept q depends on the size of the β segment under consideration. Then the algorithm histograms the stub data in (m, q) bins in 2-D array of 32x32 cells. For each column in m, a value of q is calculated,

$$q = -mr + \phi - \beta_{min}, \tag{2}$$

where β_{min} is the lower bound of the current β segment. Figure 1 shows a typical filled HT array for a β sector in dimuon event with 140 pile-up. A track is found where there is a local peak in the 2-D histogram.

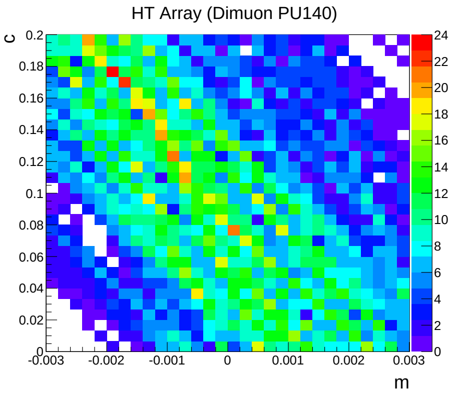

Figure 1: *A typical filled Hough Transform array for one single segment in β for one trigger region. On the z-axis number of stubs is represented. On average 120 stubs will fill this histogram, occupying 90% of cells.*

In most cases the stubs present in a HT cell are not consistent with a real track. Indeed they are usually due to random combinations of hits belonging to pile-up tracks. In order to keep only cells compatible with a high-p_T particle later filter stages are required. At the moment two different filters are applied. One operates through the binning of the radial position r, requiring that a track has stubs in at least five substantially different radii.

The other makes use of a third coordinate (η or z) not yet exploited. This filter aims to remove from the cells all the stubs that do not follow a physical trajectory in the (r, z) plane.

3.1. *Algorithm Performance*

The algorithm has been tested using simulated data samples with different signal and pile-up content. Results obtained show a good track finding efficiency, larger than 90%, except that for electron candidates, which have a lower efficiency ($\sim$ 80%). This loss is mainly due to the Bremsstrahlung effect, which deviates the electron's trajectory.

The track filtering stages significantly reduce the number of candidate cells, even if the majority of tracks found by the algorithm are due to random combination of stubs belonging to pile-up particles.

4. Firmware Implementation

The algorithm has been implemented in a systolic array within the MP7, operating at 250 MHz. At the moment of writing, a 20×20 array has been implemented, and further studies to reach a 32×32 array were ongoing. Stubs go into the array through two entry points (W-N), moving then toward east. Once filled, a cell is marked for readout when it contains stubs with at least five different radial values.

5. Conclusions

Results obtained by the software simulation demonstrate the good performance of the algorithm in track finding. The amount of track candidates found needs still to be reduced, therefore further fitting steps are currently under study.

Acknowledgments

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