Retina algorithm & Track reconstruction without magnetic field

Retina algorithm is inspired from the processing of visual images by the brain where each neuron is sensitive to a small region of the retina. The strength of each neuron is proportional to how close the actual image projected on the retina is. The purpose of retina is to find out the optimal configuration parameter to balance the sensitivity of each neuron.

In the early stage, we apply retina to a simple detector ignoring magnetic field effects and present on KC705 using both LUTRAM and fixed-point LUT approach. A more complex use case is the reconstruction of high Pt tracks in a barrel-like multi-layer detector in presence of a strong magnetic field. In the magnetic field the charge particle trajectory will bend (Eq. 1). The geometry is described as six barrel shape with six concentric circle layers with equal distance between them. The range of radius of those concentric circle layers is from 0.2 R to 1.56 R (in meter) to 1.15 R to 3.8 R (in meter) to 1.56 R to 9.36 R (in meter). All the particles will start at the center of the circles with a given initial angle, and go across six barrel layers from inner to outer. Due to the magnetic field effect, the shape of the track in the detector area is arc. So we use “Hough Transformation” change the parameter space into (θ, r), where Pt is the momentum of each charged particle and θ, is the initial direction angle of each track (Fig. 5). In the end we use retina to find out the optimal Pt and θ, for each individual track by scan the whole parameter space (cells) one by one. The Range of Pt we set to scan by retina is from 1 GeV to 50 GeV and for θ, is from 0 to 2π (in radian). Whole parameter map is divided into 400x200 cells, while 400 bins for Pt and 200 bins for θ,.

To validate the algorithm and measure its performances, hardware prototypes have been designed. From Fig. 3 you can find our first retina algorithm: online processor embeds a Floating-Point Operator IP core and a bus standard for on-chip communication ART [3], providing rapidly and easily floating-point operators that can be targeted to any of the latest Xilinx FPGA platforms.

Reconstruction of Tracks generated by GEANT4:

In order to make track reconstruction more closer to reality, we start to use GEANT4 simulation tools to setup the detector geometry and generate tracks. Then we are able to calculate the excitations R of each cell (x,y) following the function below:

\[ R = \frac{1}{\sigma} \exp \left( \frac{\sqrt{(x-x_0)^2+(y-y_0)^2}}{\sigma} \right) \]

where \( \sigma \) is a adjusted parameter for optimal response. The total response of the retina is obtained by calculating the excitations R of all cells. Finally tracks are identified by looking for a local maximum in the response array.

In the study two possible FPGA implementations of retina algorithm: one using online Floating-Point core and one using Look-up Table and fixed-point representation. Detailed measurements of the performance on hardware designs are investigated. So far the Retina has mainly be used in a detector configuration made of parallel planes, without magnetic field. Moreover we report on the simulated performance in a detector configuration made of concentric detector layers with high magnetic field (Taisla).

Conclusion and Outlook

In this note, we study FPGA-based implementations of the artificial retina algorithm for fast track reconstruction on trigger system.

In the early stage, we apply retina to a simple detector ignoring magnetic field effects and present on KC705 using both Floating-Point IP and fixed-point BLIT approaches. The performance of implementation including latency, resource, algorithm precision performance have been compared as well, which can be estimated to a complete prototype of hardware system scale.

So far, our research is targeted to adapt retina algorithm to a more realistic tracker design with cylindrical geometry. Due to the magnetic field effects, charged particle trajectories are bent and treated as partial arc. A first retina modeling of track reconstruction under the situation of particles in a magnetic field with six barrel layers tracker has been setup. Our purpose is to find out the optimal configuration parameter to balance the size of parameter space and reconstruction resolution of retina. Then change the software design into firmware design, the firmware design for this more complex use case is the reconstruction of high Pt tracks in a barrel-like multi-layer detector in presence of a strong magnetic field. In the magnetic field the charge particle trajectory will bend (Eq. 1). The geometry is described as six barrel shape with equal distance between them. The range of radius of those concentric circle layers is from 0.2 R to 1.56 R (in meter) to 1.15 R to 3.8 R (in meter) to 1.56 R to 9.36 R (in meter). All the particles will start at the center of the circles with a given initial angle, and go across six barrel layers from inner to outer. Due to the magnetic field effect, the shape of the track in the detector area is arc. So we use “Hough Transformation” change the parameter space into (θ, r), where Pt is the momentum of each charged particle and θ, is the initial direction angle of each track (Eq. 5). In the end we use retina to find out the optimal Pt and θ, for each individual track by scan the whole parameter space (cells) one by one. The Range of Pt we set to scan by retina is from 1 GeV to 50 GeV and for θ, is from 0 to 2π (in radian). Whole parameter map is divided into 400x200 cells, while 400 bins for Pt and 200 bins for θ,.

Reconstruction of curved tracks in ideal case:

A more complex use case is the reconstruction of high Pt tracks in a barrel-like multi-layer detector in presence of a strong magnetic field. In the magnetic field the charge particle trajectory will bend (Eq. 4). The geometry is described as six barrel shape with equal distance between them. The range of radius of those concentric circle layers is from 0.2 R to 1.56 R (in meter) to 1.15 R to 3.8 R (in meter) to 1.56 R to 9.36 R (in meter). All the particles will start at the center of the circles with a given initial angle, and go across six barrel layers from inner to outer. Due to the magnetic field effect, the shape of the track in the detector area is arc. So we use “Hough Transformation” change the parameter space into (θ, r), where Pt is the momentum of each charged particle and θ, is the initial direction angle of each track (Eq. 5). In the end we use retina to find out the optimal Pt and θ, for each individual track by scan the whole parameter space (cells) one by one. The Range of Pt we set to scan by retina is from 1 GeV to 50 GeV and for θ, is from 0 to 2π (in radian). Whole parameter map is divided into 400x200 cells, while 400 bins for Pt and 200 bins for θ,.

Reconstruction of curved tracks in presence of magnetic field

In order to make track reconstruction more closer to reality, we start to use GEANT4 simulation tools to setup the detector geometry and generate tracks. Then use these tracks to do track RECO.

In this case, the detector geometry is similar to the above ideal case (see Fig. 7). The configuration of track generation is shown in Fig. 7.

Single positive Muon (μ+): particle is chosen to generate the tracks. All particles will start at zero point and go across all 10 layers from inner to outer and leave there position information (hits data) on these barrel layers.

The right side of Fig. 7 shows the distribution of hits accumulated over 2000 tracks when we generated at R=2 plane, from here we can clearly see the collection structure of each barrel layer and their radius. In Fig. 8 we also give 5 tracks we generated with GEANT4 in X7 plane, here we set the Pt of Muon particle equal to 2 GeV. The trajectory of the particle is bend as an arc and turns to straight line when one enters the detector area.

The pictures above show the result of track reconstruction by Retina algorithm. Fig. 9 is the Diff_angle and Diff_Pt_inverse distribution under three different Pt of particles. Fig. 10 and Fig. 11 show the Pt and initial angle resolution against Pt of Muon particles. The definition of Diff_angle, Diff_Pt and Diff_Pt_inverse are also given at the top of Fig. 8 in red italic.

References