CMOS Pixel Sensors with on-chip Neural Network

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PROJECT INTRODUCTION

MOTIVATION

There are large lots of hits that are generated by particles that come from the beam background affecting the tracking efficiency and reducing the system bandwidth.

Features of particles coming from the background:
- Low momentum (larger incident angle on sensors)
- Enlarged cluster size (elongated shape)

Target: to tag and remove hits from the beam background versus hits from physics signals

Program: using on-chip Neural Network algorithm to classify these two kinds of hits through their charges distribution and cluster shapes \cite{1,2}

TRAINING PROCEDURE (OFFLINE)

Using the raw data and the incident angle $\theta$ to train connection weights of the neural network, to define the whole structure of the neural network (by TMVA software)\cite{3}.

Step1: Collect raw data from the output of Mimosa18 under different incident angle $\theta$

Step2: Train connection weights of the Neural Network by using raw data and incident angle $\theta$

1. Collect Raw Data

Collect sensor output raw data under $\beta$ (MSc) source with different incident angles.

Fig.3 Test bench for gathering raw data

$\theta, \varphi$: represent information of one incident particle. They are angles between the incident particle direction and the Z3 axis and X3 axis respectively.

Can not be controlled

$\alpha, \beta, \varphi$: represent the positions of the sensor. They are angles between the sensor direction and the X1 axis and Y1 axis respectively. 3D information in the test bench

Can be changed by rotating DUT in 2 axes

The relationship between $\alpha, \beta, \varphi$ is shown in the fig. 5. We can change the value of $\theta$ and $\varphi$ by changing value of $\alpha, \beta$.

Calculate angle $\varphi$ by Main Component Analysis.

$$\cos \varphi = \frac{\text{vec}M1X1}{\|\text{vec}M1X1\|^2}$$

$$\sin \varphi = \frac{\text{vec}M1X3}{\|\text{vec}M1X3\|^2}$$

$$\cos \theta = \frac{\text{vec}M2X3}{\|\text{vec}M2X3\|^2}$$

2. Train Connection Weights

1. Initialization

• Inputs and correct outputs are known.

• Structure and activation function are fixed.

• Initial weights are chosen randomly.

2. Training

• Neural networks is an iterative learning

• Calculate outputs by initial connection weights

• Errors are then propagated back, adjust connection weights.

3. End

• Neural network is used to regress output until tolerable error.

Fig 5 The relationship between $\alpha, \beta, \varphi, \theta$

Fig.4 The principle of the 2 angle rotation support

REGRESSION PROCEDURE (OFFLINE)

Using the raw data and neural network to reconstruct the incident angle $\theta$ (implemented in a FPGA device by us).

Step1: Collect raw data from outputs of Mimosa18

Step2: Reconstruct the incident angle $\theta$ by neural network and raw data

1. Collect Raw Data

Test data is a part of data which is used in training procedure

2. Calculate incident angles

- Cluster search: search cluster in raw data matrix, store input parameter of ANN, SeedCharge and TotCharge.

- Main Component Analysis (MCA): Find main direction of each cluster, calculate input parameter of ANN, RMSX$_{\text{MaxStd}}$ and RMSX$_{\text{MinStd}}$

- Shape of a cluster:

  • Maximum/Minimum standard deviation (MaxStd/MinStd) related to $\theta$

  • Orientation of the main direction related to $\varphi$ (calculate by MCA)

- Charge of a cluster:

  • Seed charge (SeedCharge ADC) of cluster related to $\varphi$

  • Total charge (TotCharge ADC) of cluster related to $\varphi$

RESULT ANALYSIS

Fig 9 shows an example of clusters that is searched by FPGA device. The regression incident angle of this cluster is 43.75 degree. Frame number of this cluster is 4500, seed pixel charge is 257 ADC unit. There is the same cluster information in regression result by TMVA software.

Fig 10 regression example by FPGA

Fig 10 shows the difference between the obtained mean values of $\theta$ from neural network and the real incident angles $\theta$. The blue one is obtained from NN by TMVA and the red one from NN by FPGA device. The results of the FPGA regression are basically the same as the software (TMVA) regression results.

PERSPECTIVES

- Based on the system, gather more data, train accurate weights value of the neural network.

- Design new feature extract algorithm to represent cluster information.

- Design an algorithm of on-chip cluster search.

- Optimize the power consumption and size of the design.

REFERENCES

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