Efficient Level 2 Trigger System Based on Artificial Neural Networks

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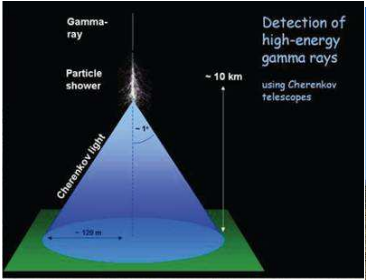
Contents

Context

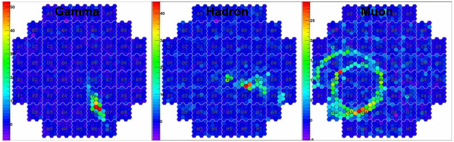
The HESS Project

- Objectives
  → Detection of High-energy gamma rays
  → Collecting interesting events (gammas) and reject all others (Protons, Muons)
- Based on 4 Cherenkov Telescopes located in Namibia
  → Cherenkov light
  - As a high energy cosmic ray particle hits the atmosphere it creates an extensive air shower by interaction with the atmosphere.



Examples of collected images

- After HESS1 trigger, only binary information available for each Pixel $\rightarrow$ A decision regarding the nature of a particle is difficult to make
- The HESS collaboration has decided to improve the performances of this project in a new version (HESS 2)



HESS2

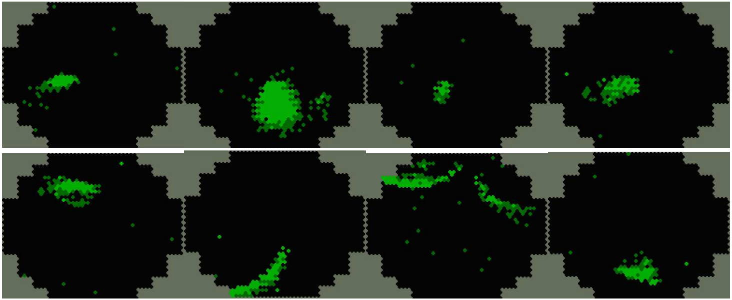
- Objectives
  → Improve the HESS1 experiment by
  - Adding a new HESS2 event class(E from 10GeV to 50GeV)
  - Increasing sensitivity for E$\sim$50 to 100GeV
  - Improving resolution for E$>$100GeV
- Means
  → A Very Large Cherenkov Telescope added in the center of the 4 existing ones
  - Much more collected information
  - Possible Stereoscopy

HESS2

- Issues
  $\longrightarrow$ Huge amount of data to be processed on-line
  - 240 GBauds in approximately $10\mu s$
- Envisaged solution
  $\longrightarrow$ Efficient Trigger system to minimize the data flow
  $\longrightarrow$ Adding a Level 2 trigger to make a decision about the interest of a physical event

Examples of simulated images (HESS2)

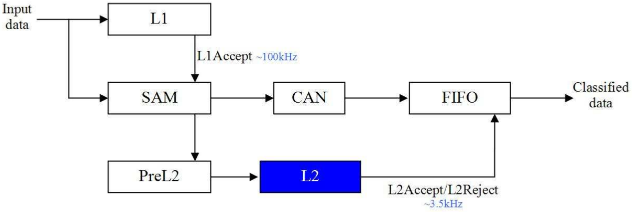
- Observations



- Finest granularity
  → 2048 pixels (instead of 960 pixels)
- More Information
  → 3 levels of energies per pixels (instead of 2)

The global HESS2 Trigger System

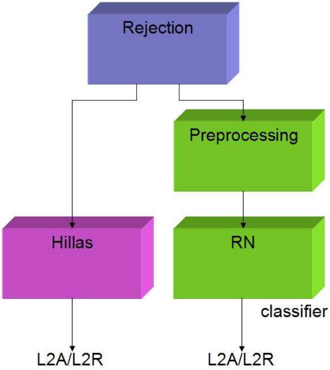
- The trigger System is Composed of 2 levels :
  → L1 : eliminates the NSB
  → L2 : classifies particles (G,M,P)
- Input data are stored in a analog memory(SAM)
- L1 applies threshold on the images and delivers a L1A/L1R signal (100KHz).
- PreL2 thresholds the L1A images and transmits the resulting images to L2.
- L2 implements more complex processing on the incoming images and generates a L2A/L2R signal (3,5 KHz).



The Level2 Trigger

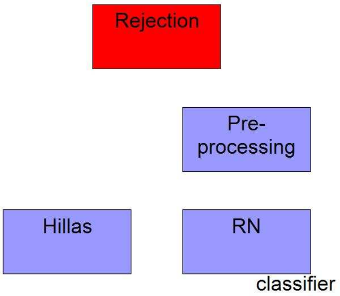
- Goal :
  → Implement pattern recognition algorithms to accept photons and reject all other particles
  → Generation of a L2A/L2R signal
- Structure :
  → Multilevel processing chain
  - Pipelining
  - Multiple decisions

  → Latency
  - A window of 10μs is available to compute all the algorithms.
- Two approaches :
  → Filter based on Hillas parameters (classical method)
  → Neural System



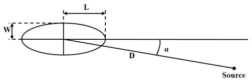
The rejection block

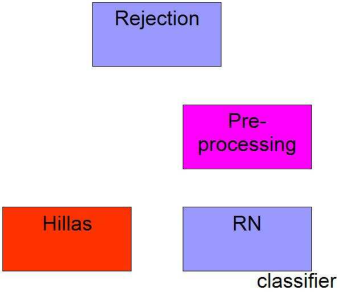
- Common to both approaches
- Goal :
  → Reject all images that contain less than 4 active pixels
  → Because it is difficult to make a decision with such poor information



1st classical approach : Utilization of Hillas parameters

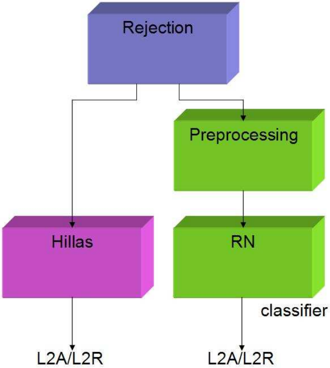
- Principles
  → According to the particles signature, the idea is to adjust a bidimensional ellipse on the image
  → Compute the COG, length, width, surface, area and α
  → According to the obtained parameter values, classify the particles in 3 classes (G,M,P)
- As neural network input
  → 5 inputs.





2nd approach : The Neural solution

- Input
  → Images containing more than 4 pixels
- Composed of 2 stages
  → Preprocessing
  → Neural classifier
  - L2A/R generation

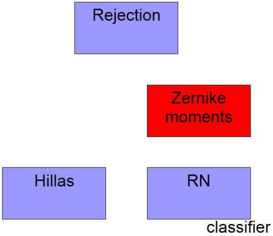


Neural solution (preprocessing)

- Role
  $\longrightarrow$ Rotation and translation invariance.
  $\longrightarrow$ Small number of parameters describing the images.
- Description
  $\longrightarrow$ Efficient in terms of feature representation capability and low noise sensitivity
  $\longrightarrow$ Moment of order p, repetition q :

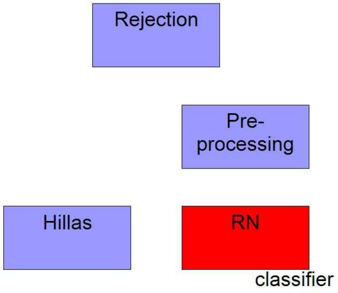
$$Z_{pq} = \frac{(p+1)}{\pi(N-1)} \sum_{x=1}^{N} \sum_{y=1}^{N} V^*_{pq}(r,\theta) f(x,y)$$

with : $r = \frac{(x^2+y^2)^{1/2}}{N}$ and $\theta = \tan(y/x)$,
$V_{pq} = R_{pq}(r) e^{iq\theta}$
$\longrightarrow$ Until order 8 (25 parameters)



Neural solution (classifier)

- Structure
  → Classical Multi-layer Perceptron
  → Number of inputs corresponding to the preprocessing
  → 3 outputs corresponding to the 3 classes to identify
  - Gamma
  - Muon
  - Proton
- Neural Networks Properties
  → Powerful computational model
  → Inherent parallelism=> Suitable for hardware implementation



Results

- Comparisons between both approaches in terms of rejection rate
  → Mean on all energies
  → On the same data
  → NN System
  → Hillas Parameters
- Performances of NN with Zernike are better than those of Hillas filter or NN with Hillas.

	Gamma	Muon	Proton
Hillas filter	60%	56%	37%
NN with Hillas	71%	84%	82%
NN with Zernike	95%	58%	41%

	Gamma recognized	Hadron recognized
NN with Hillas	76%	80%
NN with Zernike	85%	70%

Conclusion and persepectives

- Hillas approach is satisfactory
  $\rightarrow$ Fast computation
  $\rightarrow$ But strong cuts in the final decision
- The neural approach has already shown efficient results in Physics experiments
  ≪The H1 Neural Network Trigger Project≫ ACAT 2000
- Satisfying results in the HESS2 project
  $\rightarrow$ Dimension reduction of the parameters space
  - Exploit images properties to help the NN in its tasks (Zernike moments)
  - Get information from the Hillas parameters

  $\rightarrow$ Faster computation of the NN

Conclusion and perspectives

- Hardware implementation of the L2 algorithms
  $\rightarrow$ Strong real time constraints (10μs) to execute the neural system (preprocessing + NN)
  $\rightarrow$ Develop an optimal (massively parallel) hardware architecture to implement
  - Preprocessing
  - Classifier

  $\rightarrow$ Target implementation chip such as FPGAs
  - Very fast circuits
  - Flexible