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Machine Learning to improve the sensitivity of the MAGIC telescope

Introduction

The Major Atmospheric Gamma ray Imaging Cherenkov telescopes (MAGIC) are located at the Roque de los Muchachos Observatory, La Palma in Spain. It consists of two twin telescopes, MAGIC I and MAGIC II, which are both reflectors with 17m diameter. The camera of the MAGIC telescope are composed by 1039 photomultiplier tubes (PMTs), they converts signal collected into optical and sent to the counting house through optical fibers. Then the signal is then converted into electrical signal and send to a three-level signal branch. Due to the large collection area of the MAGIC telescopes, it is able to observe photons in a low threshold of about 25 GeV. Moreover, the MAGIC telescope is currently the most world's most sensitive instrument in detecting energy range of 30GeV to 100GeV.

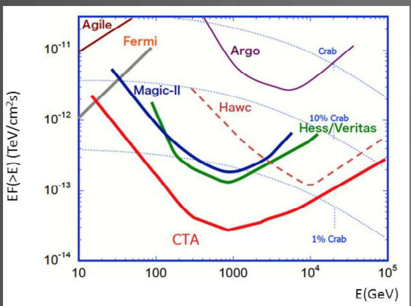

Fig 1. The sensitivity curve of different gamma ray instruments, showing the MAGIC is the world's most sensitive instrument as the CTA is yet to be in full operation

Fig 2. The two MAGIC telescopes

Background knowledge

1. Cosmic rays and gamma rays

Cosmic rays are high energy charged particles (e.g. atomic nuclei) that can be produced by both galactic or extragalactic objects. As they are charged particles, they interacts with magnetic fields they encounter in the way to Earth and because of this reason, they carry no information about the event which originate them.

Gamma rays are the most energetic photons in the electromagnetic spectrum. They can be produced by several astronomical sources and processes such as gamma ray bursts or pulsar emission. Unlike cosmic rays, gamma rays are not electrically charged therefore their paths are not affected by intergalactic magnetic field. As a result, they contain information of their origin and they can be used to study very high energy objects in the universe.

2. Extensive air showers and Cherenkov Radiation

The atmosphere of the Earth is not transparent to cosmic rays and gamma rays, therefore when they enter the atmosphere, they will interact with atmospheric nuclei and set off a chain-reaction particle cascade, called the extensive air showers.

Although the mechanisms behind interaction with atmospheric nuclei for cosmic ray and gamma ray are slightly different, both of them generates relativistic charged particles. When a charged particle moves through a medium faster than the speed of light in that medium, it generates Cherenkov radiation. Cherenkov radiation is an analogy of shock waves generated when aircraft moves faster than the speed of sound in the air, it travels like a cone with following the direction of particle motion. The MAGIC telescope detects the Cherenkov photons and reconstruct information about the particle that initiate the shower.

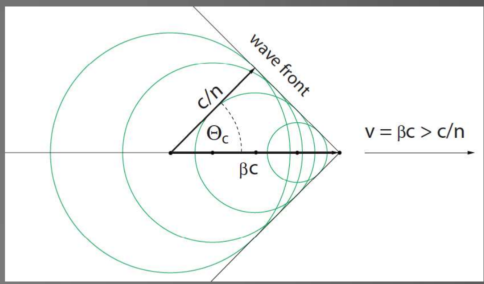

Fig 3. Schematic view of the light cone emitted during Cherenkov radiation

Methodology and discussion

It is hard to distinguish between Cherenkov light generated by gamma ray and those generated by cosmic ray. Even observing a bright gamma ray source, the signal-to-noise ratio is lower than 1%.

In order to tackle the problem, we try to adopt a machine learning approach on analysing the data of the MAGIC telescope. Machine learning is a subject of computer science that aim to solve regression and classification problems with the system having the ability to improve and learn without explicitly having human intervention for tuning parameters of model. With the availability of large dataset of Monte Carlo simulations and real data from the MAGIC telescopes, a convolutional neural network is used for better analysis of the event.

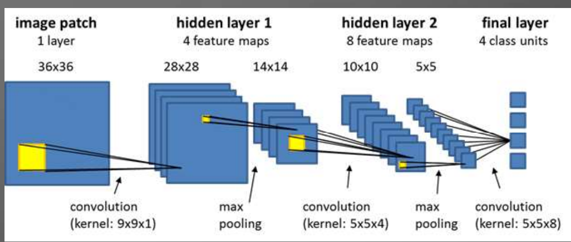

Fig 4. The algorithms of convolutional neutral network

However, any parametrization on the data implies information loss. To further the research, it is still necessary to construct a new algorithm using machine learning to avoid parametization.

Reference

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