Application of pattern spectra and convolutional neural networks to the analysis of simulated Cherenkov Telescope Array data

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cherenkov telescope array

ABSTRACT

The Cherenkov Telescope Array (CTA) will be the next generation gamma-ray observatory and will be the major global instrument for very-high-energy astronomy over the next decade, offering 5 - 10 x better flux sensitivity than current generation gamma-ray telescopes. Each telescope will provide a snapshot of gamma-ray induced particle showers by capturing the induced Cherenkov emission at ground level. The simulation of such events provides images that can be used as training data for convolutional neural networks (CNNs) to determine the energy of the initial gamma rays. Compared to other state-of-the-art algorithms, analyses based on CNNs promise to further enhance the performance to be achieved by CTA.
Pattern spectra are commonly used tools for image classification and provide the distributions of the shapes and sizes of various objects comprising an image. The use of relatively shallow CNNs on pattern spectra would automatically select relevant combinations of features within an image, taking advantage of the 2D nature of pattern spectra. In this work, we generate pattern spectra from simulated gamma-ray events instead of using the raw images themselves in order to train our CNN for energy reconstruction. This is different from other relevant learning and feature selection methods that have been tried in the past. Thereby, we aim to obtain a significantly faster and less computationally intensive algorithm, with minimal loss of performance.

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1 - Introduction

The interaction of a gamma ray with the Earth atmosphere induces a particle shower, which produces a flash of Cherenkov light. The Cherenkov Telescope Array (CTA) will be able to capture the Cherenkov emission at ground level, which provides information about the energy of the initial gamma ray. Pattern spectra are commonly used tools for image classification, which provide the distributions of the shapes and sizes of various objects comprising an image and can be used as a tool to reconstruct the energy of the initial gamma ray.

2 - Analysis

The pattern spectra are generated from 8-bit CTA images due to current software limitations. Separately, the original CTA images, the 8-bit CTA images, and the pattern spectra are used as an input for a convolutional neural network (CNN), which is trained and tested for energy reconstruction.

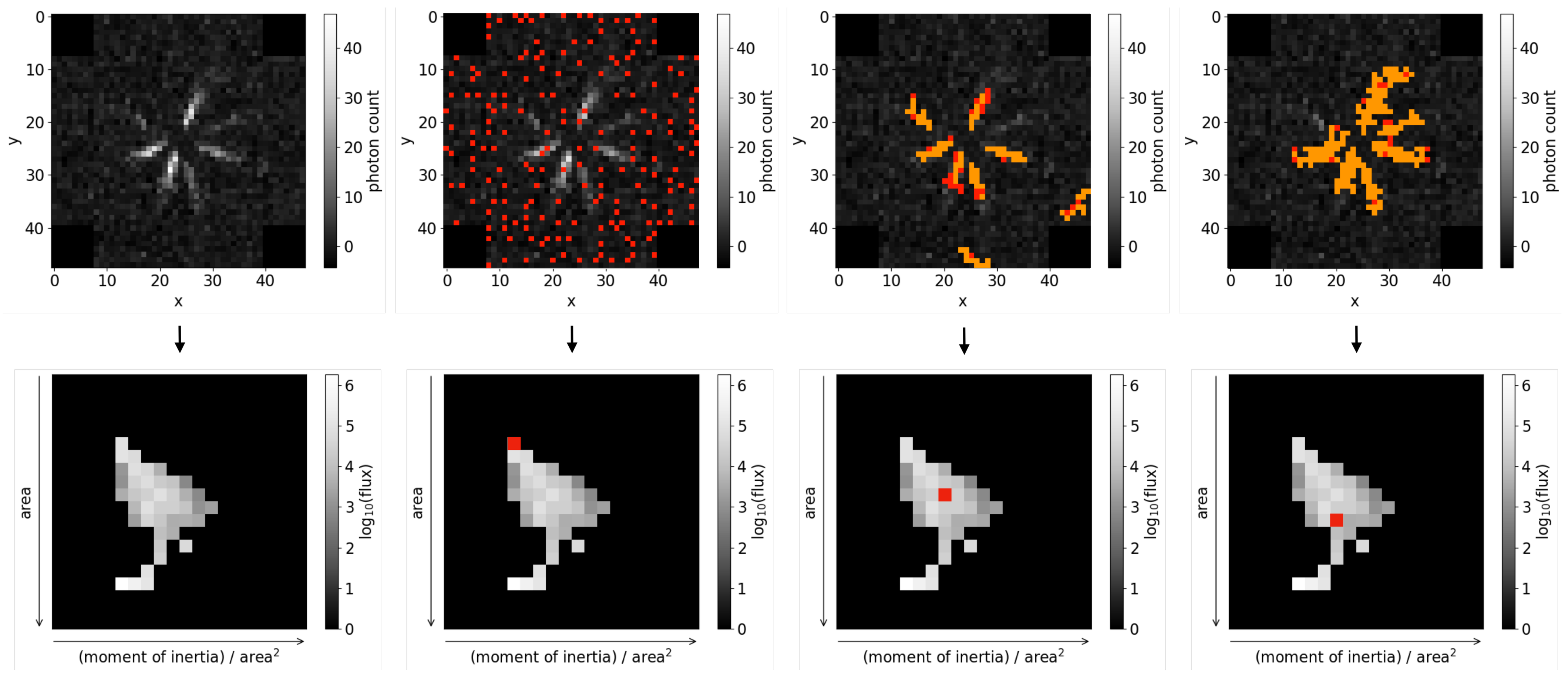

Fig. 1: Top: 8-bit CTA images with highlighted features (in red/orange) detected by the pattern spectra software. Bottom: pattern spectra with the pixel (in red) corresponding to the detected features.

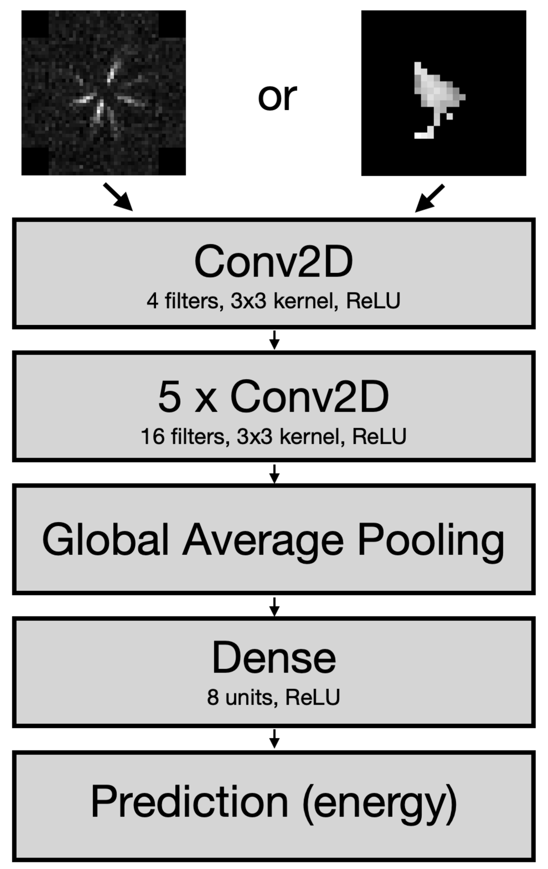

Fig. 2: CNN architecture

4 - Results

In all cases, the CNN is able to reconstruct the energy of the initial gamma ray for the majority of events. The energy resolution obtained from the original CTA images and 8-bit CTA images outperforms the analysis based on pattern spectra for all energies. During training, the CNN based on pattern spectra needs 65 % less maximum RAM and is 41 % faster compared to the CNN based on the original CTA images.

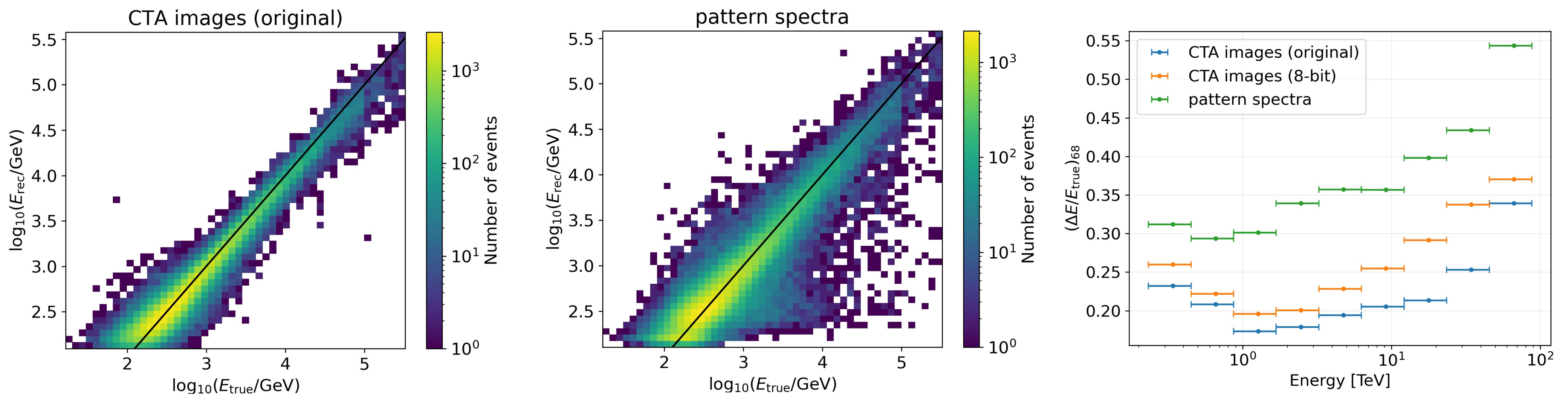

Fig. 3: Reconstructed energy E_{rec} as a function of true energy E_{true} obtained with the original CTA images (left) and pattern spectra (middle). Energy resolution comparison (right).

4 – Discussion

For the first time, the energy of gamma-ray events was reconstructed by applying pattern spectra on a CNN. The fact that the pattern spectra based analysis is currently not achieving the same accuracy as the original CTA images based analysis can partly be explained by the loss of information during the conversion of the CTA images into an 8-bit image before they can be put into the pattern spectra software. The significant reduction in computational power and time needed to train our CNN indicates that pattern spectra have potential in full gamma-ray event reconstruction analyses based on CTA data.

Tab. 1: Computational performance of the CNNs based on (a) original CTA images and (b) pattern spectra during training

	CTA images	Pattern spectra	1 – ratio
Max. RAM	30.26 GB	10.60 GB	65 %
Time	7176 s	4220 s	41 %

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