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Background Rejection using Convolutional Neural Networks

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Abstract. The paper presents a proof of concept method of background rejection based on convolutional neural networks (CNN). The method was tested on simulated data and achieved very high accuracy (100%). What is more, method based on CNN is very fast and could be easily applied to wide field surveys. Since early stage results suggest method is very accurate and robust, it could be helpful in creating very low-latency pipelines for EM Follow-up purposes, which will be needed in LIGO-Virgo O3 EM Follow-up.

Keywords. Convolutional Neural Networks, Electromagnetic Follow-up, Background Rejection

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1. Introduction and Motivation

For effective searching for electromagnetic counterparts, to gravitational waves (GW) detected by LIGO-Virgo detectors, the most important is to successfully identify a optical transients on images taken by the telescopes. Typically for each event detected by the network of three GW detectors for O2 LIGO-Virgo science run an area of the sky to be searched is around ∼100 *sq.deg* (Abbott *et al.* 2017). This is a challenge even for a big field of view telescopes. If transient is identify early enough it gives an opportunity to other telescopes to make a more detailed follow-up and taking spectra. There is a clear need of a fast and very reliable system for distinguishing, real optical transients (OTs) from background events (bogus transients), that could be used for low-latency analysis. Such system could be used for wide deep survey like TOROS (Díaz *et al.* 2017).

2. Proof of concept method

<u>*Current methods*</u> based on Laplace transform are considered the most commonly used. But those methods not always could distinguish correctly between real and bogus events. Since, in border cases human inspection of images is the final criteria, it seem to be to important to check, if methods based on neural network could be used on top of standard methods. Especially worth considering are convolutional neural networks widely used for image processing. In case of papers describing background rejection methods (van Dokkum 2001, Bailey *et al.* 2008), it is suggested that neural nets (not CNNs) are much worse than other methods (for example Laplace transform). But it has to be noted that those articles (van Dokkum 2001, Bailey *et al.* 2008) considered normal neural nets. It seems that apart from Cherenkov telescopes, neural nets (but not CNNs) (Bernlhr *et al.* 2013) are not used for background rejection. CNN types of networks are used for classifying radio galaxies (Aniyan & Thorat 2017).

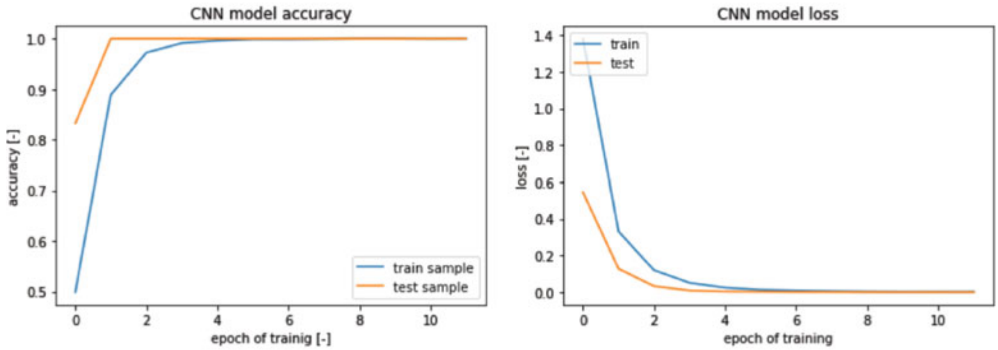

Figure 1. Accuracy (left) and loss (right) of classification done by CNN vs. training epoch.

Structure of CNN. Proof of concept method using CNN was build to classify, if an object is real optical transient or a bogus transient event. All code was written in python 2.7 programming language. For constructing neural network models a Keras package with Theano backend was used. The model of network was constructed using following layers: 2D convolutions along with 2D max polling (2x), flatten (1x), dense (3x).

Training of the network. The network was trained and tested using simulated telescope data. Input for the network was 21 by 21 pixels stamp image of potential optical transient. Image consisted of an object and surrounding background. There was no other source on the stamp image. There were six classes of possible objects: real optical transients, noisy background, hot pixel, cosmic rays, saturation from bright star and artifacts from badly opened shutter. Both train and test samples consisted of 8000 simulated cases divided into six classes. This corresponds to roughly 1333 cases per class. Network was trained using 12 epochs. The trained CNN was able to positively classify all cases, which means that probability of error is less than 1/8000. What is more method turned out to be very fast. One thousand cases was analyzed by CNN in 350 ms on laptop Core i7 processor. The proof of concept shows that based on CNN very accurate and fast methods for background rejection could be build.

Further Work. The developed method has to be tested on real data with injected artificial optical transient. In the next step it would be tested on real data from telescopes of TOROS collaboration. If above tests are successful, the method could be implemented into TOROS data analysis pipeline to make low-latency analysis more accurate for EM Follow-up.

3. Summary

A proof of concept method for rejecting background events transients using Convolutional Neural Network proven to be efficient and reliable. The method was tested on simulated data. The artificial neural network used in the method have reached 100% classification rate of real/bogus transients on 8000 samples. Very high accuracy of this solution suggest that classification methods based on CNN's could be used for low-latency image analysis for LIGO-Virgo's EM Follow-up related observations, and could allow automated EM counterpart discovery and GCN issuance.

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