Lightning Waveform Classification Based on Deep Convolutional Neural Network

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Abstract

With the application of lightning data in meteorology, electric power as well as public safety, massive lightning data is accumulated. Meanwhile, a synthesized and complicated problem arose, which is, how to automatically obtain the valuable information from the massive lightning data. The deep learning method provides an effective way to automatically classify the event type of lightning discharges from raw lightning data. In this paper, we propose a five-category classification model for the raw lightning waveforms in VLF/LF bands. The model is based on deep convolutional neural network, which is trained and tested by a six year (2012-2017) data set that comprised of over 30000 lightning events. We did experiment with different layers of networks and found that the 7-layer network gives the best performance. The output of the classifier is a five-element vector which shows up the results of different lightning type. Due to the multi-layer stacking of the convolutional network, higher-order features can be better extracted. Furthermore, the model we proposed can effectively identify the cloud-to-ground (CG) flash, ordinary intracloud (IC) flash, preliminary breakdown pulse (PB), narrow bipolar event (NBE), and especially the error rate on CG is less than 3%. Finally, we apply the classifier to the lightning data set for 2017 and group identified return stroke into flashes by hand to qualify the accuracy-stroke-study data of CG flashes. Based on the flashes, we present the characteristics of cloud-to-ground lightning flashes in four isolated small thunderstorms.

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1. Introduction

In this study a deep convolutional neural network is used to analyze the low-frequency time domain waveform of lightning discharges, which achieves more than 95% recognition accuracy for various types of lightning discharges. The method greatly reduces the workload of manual recognition for lightning discharge types, and enables efficient processing of numerous lightning data by machine.

The method was applied to data from five isolated thunderstorms and its recognition accuracy of return strokes was evaluated by comparing with results recognized by hand.

2. Data

The data used in this study were obtained from the Jianghuai Area Sferic Array(JASA), a twelve-station local network, which are operated in Anhui Province, east of China. JASA is an array of VLF/LF receiver consisting of an electric field change antenna, with a bandwidth from 800Hz to 400kHz. Each station was equipped with a GPS receiver to tag the lightning event time with an accuracy of better than 200ns and collects lightning signals with no-dead time.

Lightning discharges are classified into five types, including negative cloud-to-ground flashes (NCG), positive cloud-to-ground flashes (PCG), narrow bipolar event (NBE), preliminary breakdown (PB), and ordinary intra-cloud flashes (IC). Figure 1 illustrates the typical waveforms of different lightning discharges.

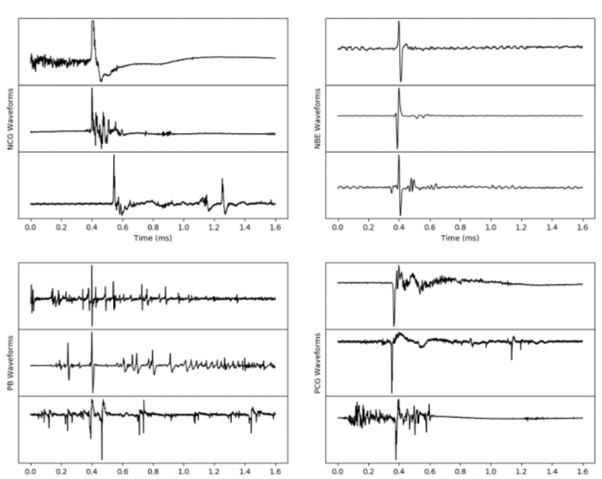


Figure 1: Different types of lightning discharges

3. Methodology

This study constructs a lightning discharge type recognition model based on one-dimensional convolutional neural network. As shown in Figure 2, the architecture of neural network consists of 7 convolutional layers and 4 max-pooling layers. The network was given a name Lightning-Net.

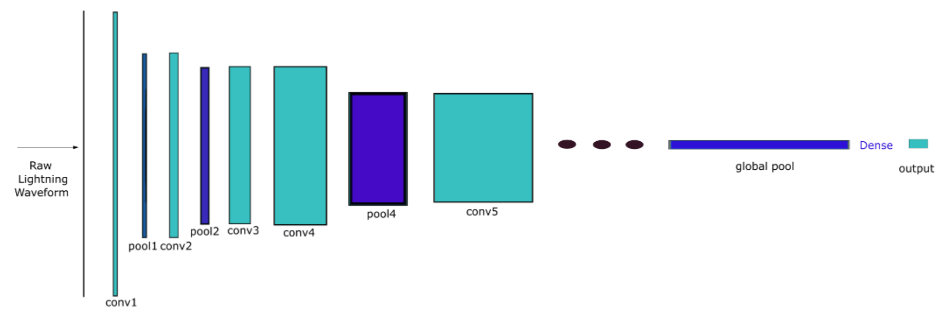


Figure 2: CNN architecture for lightning waveform recognition.

A train set including 30,000 hand-picking lightning events was used to train the network and a test set including 3000 events was used to testify the recognition accuracy of the network. We examined neural networks of different layers, and found that the neural network with 7 layers had the best performance. Figure 3 compares the recognition accuracy between 7-layers and 5-layers network under different epochs, which implies that 50 epochs can achieve a recognition accuracy better than 95%.

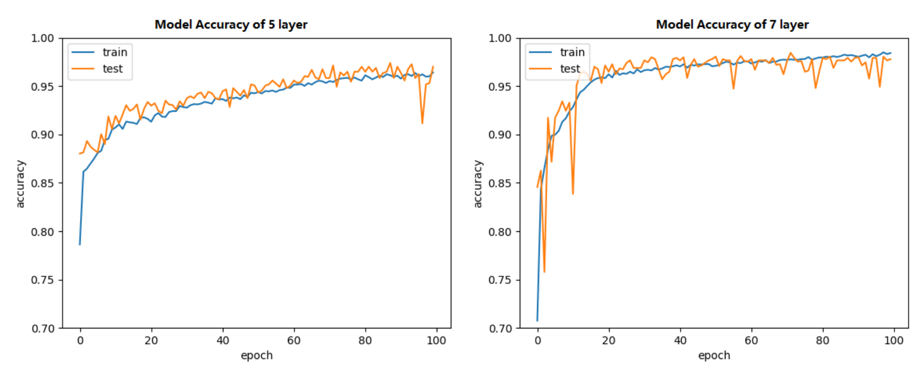


Figure 3: The comparison of 5-layers and 7-layers on accuracy

4. Results

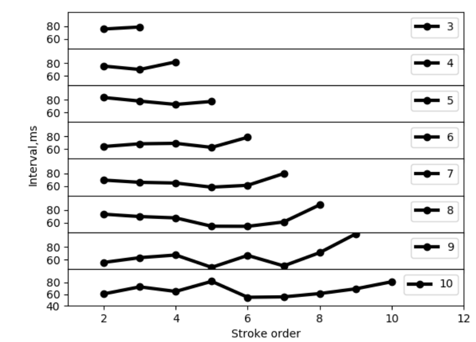
Five isolated thunderstorms were cautiously selected for the analysis of NCG. As shown in the Table 1, the geometric on the characteristics mean of inter-stroke interval is about 70ms. In addition, the number of strokes per flash ranged from 2.2 to 4.0 respectively in five thunderstorms. The percentage of single-stroke flashes accounts for more than 30% based on the complete cloud-to-ground flashes in five thunderstorms.

Table 1: Percentage of single-stroke flashes and average multiplicity in five isolated small thunderstorms

Storm ID	Total number of flashes	Number of strokes	AM/ms	GM/ms	Percentage of single-stroke	Average multiplicity	Accuracy
Hefei,0713	433	1120	89	71	43.3%	2.5	98.9%
Hefei,0729	223	500	86	64	57.3%	2.2	98.8%
Hefei,0805	801	2724	91	69	35.4%	3.4	99.1%
Hefei,0810	170	488	94	73	44.7%	2.8	99.1%
Hefei,0815	115	461	103	76	30.4%	4.0	99.3%
Total	1742	5293	92	70	40.7%	3.0	99.1%

The correspondence between the interval and order is shown in Figure 4, showing an increasing tendency for inter-stroke intervals of the last few orders of stroke.

Figure 4: Distribution of inter-stroke intervals as a function of stroke order for CG flashes of different multiplicities



5. Conclusions

In this work, a classification model based on CNNs was introduced to classify lightning time domain waveform and an average recognition accuracy better than 95% was expected. Moreover, the recognition accuracy of NCG flash for five thunderstorms was verified to better than 98%, indicating that the method is effective and feasible.