IJEPEM

Int. J. of Environmental Pollution & Environmental Modelling, Vol. 1(3): 58-62 (2018)
(Review Paper)

Air Pollution Modelling with Deep Learning: A Review

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Received July 28, 2018; Accepted September 20, 2018

Abstract: Air pollution is one of the fundamental environmental problems of the industrialized world due to its adverse effects on all organisms. Several institutions warn that there exist serious air pollution in many regions of the world. When all devastating effects of air pollutants considered, it is crucial to create valid models to predict air pollution levels in order to determine future concentrations or to locate pollutant sources. These models may provide policy implications for governments and central authorities in order to prevent the excessive pollution levels. Though there are a number of attempts to model pollution levels in the literature, recent advances in deep learning techniques are promising more accurate prediction results along with integration of more data. In this study, a detailed research about modelling with deep learning architectures on real air pollution data is given. With the help of this research we attempt to develop air pollution architectures with deep learning in future and enhance the results further with insights from recent advances of deep learning research such as Generative Adversarial Networks (GANs), where two competing networks are working against each other, one for creating a more realistic data and the other one to predict the state.
Keywords: Deep learning, air pollution estimation, artificial neural networks, generative adversarial model.

INTRODUCTION

Since the industrial revolution air quality of the world has been changing rapidly. Most of the industrial activities emits huge amounts of toxic or harmful pollutants to the atmosphere such as SO_2, NO_2, CO, PM and toxic organics. Most of these air pollutants affects people seriously along with animals and plants. For example, respiratory, cardiological and pulmonary problems by inhalation are some of these problems created by air pollutants. They may also lead to more serious problems affecting whole world such as global warming and climate change. When all negative effects of air pollutants considered, it is very important to model air pollution to determine future concentrations and pollutant sources.

There are several modelling methods have been implemented for this purpose. Artificial neural networks are one of the mostly chosen techniques which based on machine learning. Deep learning is sub-cluster of machine learning. It carries artificial neural networks one step beyond with using huge data set, solving problems without dividing, using more layers, processing simultaneously with sequential layers and providing more trustable results. All these favourable features of deep learning make it suitable method for air pollution modelling. In order to develop successful model, several steps should be followed. In this work, modelling with deep learning architectures on real air pollution data was explained in detail by considering the recent advances in this area and the differences with other artificial intelligence models. Also, the development of deep learning model was indicated step by step and results of different studies were given for the comparison.

DEEP LEARNING CONCEPT

In general, artificial intelligence was developed in the 1950s and it is an older concept than machine learning. Artificial intelligence is one of the mostly used modelling approach used for environmental issues. AI works as a human brain and uses these several features [1]. For instance, human brain has many incredible characteristics such as massive parallelism, distributed representation and computation,

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This paper has been presented as an oral presentation at International Conference of Ecosystems (ICE2018), Tirana, Albania, June 22-25, 2018. This is modified version of conference paper.

learning ability, generalization ability and adaptivity. Also, artificial intelligence uses the same method as human brain uses to solve perceptual problems.

Besides, machine learning (ML) has started to be seen in the 1980s and has become one of the basic stones in the present technology. Machine learning is a method used to devise complex models and algorithms such as prediction, classification, clustering [1]. One of the mostly used method in prediction of air pollutants is Artificial Neural Networks (ANN). In ANN computations are structured in terms of an interconnected group of artificial neurons, processing information using a connections approach to computation.

After 2010, the concept of deep learning (DL) has taken place of machine learning. Deep Learning is a subfield of machine learning concerned with algorithms inspired by the structure and function of the brain called artificial neural networks [1]. It uses many non-linear processing unit layers for feature extraction and transformation. These layers follow one after each other [2]. At the end, they create competition with high accuracy. In Figure 1, development steps of AI, ML and DL according to the years are given.

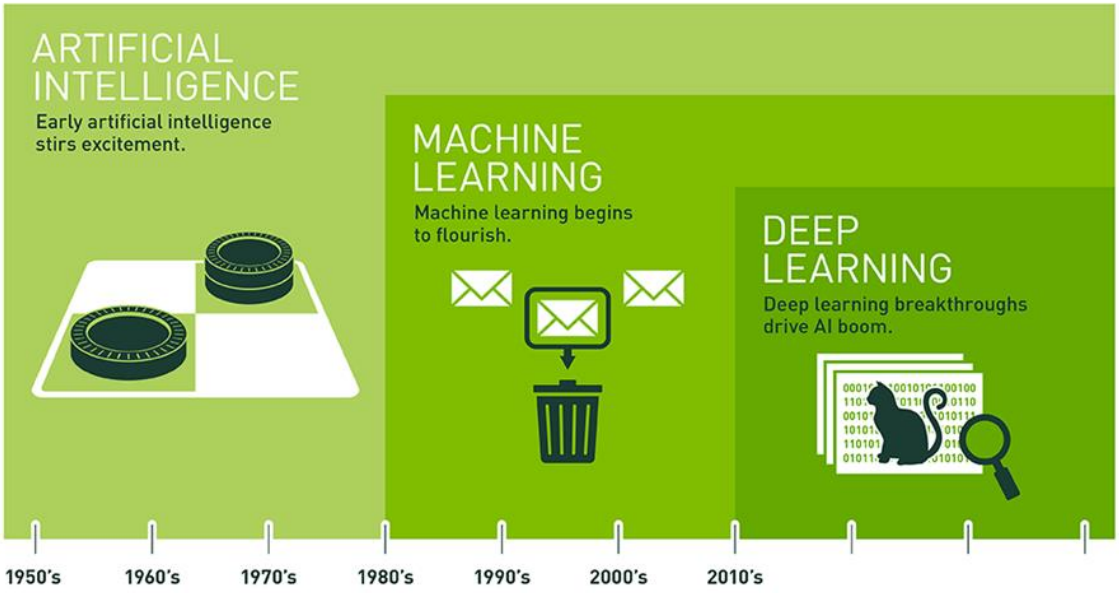

Figure 1. Development steps of AI, ML and DL according to the years [1]

The main differences between machine learning and deep learning may be explained with two matter. First one is the size of data and the second one is the problem-solving methods. In deep learning big data is used when it is compared with machine learning. Deep learning focus on end to end problem solving while machine learning uses divide and manage the problem method. Furthermore, deep learning makes simultaneous process in sequential layers while machine learning makes process in a single layer.

Most of the deep learning models are developed by following several steps such as input and output vector determination, transfer function determination, network structure selection, number of hidden layer determination, weight specification and learning algorithm selection. In order to create a prediction model with deep learning, following steps should be implemented:

- Definition of the relevant data sets and preparation of them for analysis
- Selection of the algorithm to be used
- Creation of an analytical model based on the algorithm used
- Training of the model in the test data sets and running the model to generate test scores
- Generation of a forward prediction based on the result

The general structure of the deep learning model consists of the input, hidden and output layers. Each of these layers should be weighted with a numerical value [3]. The neurons in hidden layer are affected from input and output neurons, learning algorithm, network structure and type of activation function [4,5]. In order to determine the number of neurons in the hidden layer, it is necessary to train the different networks and approach the error in the test data [5].

Also, when the environmental problems considered, deep learning has ability to find location of pollution sources, detect the areas in which the pollution levels are high and predict the future concentrations.

AIR POLLUTION MODELLING WITH DEEP LEARNING

There are several modelling techniques appropriate for air pollution prediction such as, long short-term memory (LSTM) model, spatio temporal deep learning (STDL)-based air quality prediction method, deep air learning (DAL) and Convolutional Neural Network (CNN). Especially LSTM method is the mostly used one for this purpose [6,7]. LSTM models are the part of recurrent neural networks (RNN) which uses a framework for future forecasting and the pollution and meteorological information of time series data [7]. In LSTM model, a memory blocks are used instead of neurons in hidden layer of standard RNN. In the block system of LSTM, there are input gate, forget gate and output gate providing the information flow between in and out of cell [6]. In Figure 2, block system of LSTM is given.

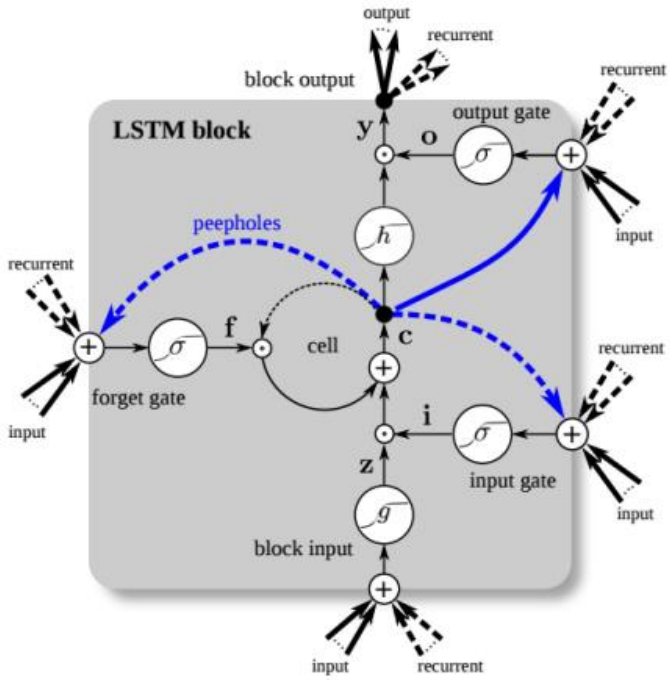

Figure 2. Block system of LSTM models [6]

The other mostly used method in this context is STDL method which considers spatial and temporal variations for prediction. Stacked autoencoder models are used as an introduction model for remove inherent air quality features. Main idea behind stacked autoencoder is connected output layer of autoencoder stacked in below layer is wired to the successive input layer [8].

Moreover, spatio temporal data are used for increasing prediction performance in DAL models which mainly uses feature selection and semi-supervised learning. DAL is an effective approach which also include spatio temporal semi supervised learning and feature selection in the input and output layers [9].

Furthermore, CNN models are also used for air quality modelling by using photos. This model includes two basic ingredients such as negative log-log classifier increasing the ordinal discriminative

ability of the model and the Rectified Linear Units (ReLU) activation function which is developed for photo-based air pollution estimation [10].

COMPARISON THE RESULTS OF DIFFERENT STUDIES

There are several studies which were modelled with deep learning to predict future concentrations of air pollution. In Table 1, previous studies about air pollution estimation are given. According to this table, models developed with LSTM have given promising results. Moreover, RMSE values represent the success of the models and more efficient results have been taken by study of Qi et al. In models constructed using different algorithms for long and short time periods, more successful results were obtained for short time periods.

Table 1. Previous studies conducted with deep learning for air pollution estimates

Modelling Method	Pollutants	Prediction Performance	Evaluation Criteria	Reference
LSTM	PM2.5	RMSE 12.41 (8 hours) RMSE 13.54 (24 hours)	Root Mean Square Error (RMSE)	[11]
LSTM	O_3, NO_2	RMSE 3.26 (O_3) MAE 2.81 (O_3) RMSE 3.76 (NO_2) MAE 3.11 (NO_2)	RMSE, Mean Absolute Error (MAE)	[6]
LSTM	PM2.5	RMSE 44.15 (5 hours) R2 0.689 (5 hours) RMSE 108.14 (120 hours) R2 -0.328 (120 hours)	RMSE, R2	[7]
STDL	PM2.5	RMSE 14.96 MAE 9.00 MAPE 21.75%	RMSE, MAE, Mean Absolute Percentage Error (MAPE)	[8]
DAL	PM2.5	RMSE 0.0667 (1-12 hour) RMSE 0.0877 (37-48 hour)	RMSE	[9]
CNN	PM2.5, PM10	AE 0.606 (PM2.5) AE 0.411 (PM10)	Average Error (AE)	[10]

CONCLUSION AND FUTURE WORK

Air pollution modelling with deep learning is a new concept. The future prediction of air pollutants conducted with deep learning may reach nearly exact results. With the help of deep learning the lack of relevance to air pollution forecasting may be decreased and, in this area, larger projects may be developed. For the air pollution prediction with deep learning, different types of big data such as photos, sounds and numeric data can be used. LSTM, STDL, DAL and CNN are some example methods used for this purpose. Their efficiency mainly depends on data and algorithms used. When the deep learning

models for air pollution estimation are compared with other methods like artificial neural networks and fuzzy logic, it creates more successful results.

We also would like to point out a promising direction for air pollution prediction problem: Recent studies have proven generative adversarial networks (GANs) be very successful in generating content via two competing networks: One for generating synthetic forecasts and the other network classifying the genuine data from synthetic data. The dynamics among these two networks are expected to provide a model with superior predictive power compared to the state-of-the-art deep learning techniques. Our insight for this expectation is as follows: It is important for the predictive models to learn how real data behave, but they tend to provide enhanced results if the model is provided how the real data does not behave in the presence of sophisticated data synthesizers.

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