Numerical, Machine Learning and Deep-Learning based Framework for Weather Prediction

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Abstract
Weather forecasting has become a very popular topic nowadays among researchers because of its various effects on global lives. It is a technique to predict the future, what is going to happen in the atmosphere by analyzing various available datasets such as rain, snow, cloud cover, temperature, moisture in the air, and wind speed with the help of our gained scientific knowledge i.e., several approaches and set of rules or we can say them as algorithms that are being used to analyze and predict the weather. Weather analysis and prediction are required to prevent nature from natural losses before it happens by using a Deep Learning Approach. This analysis and prediction are the most challenging task because of having multidimensional and nonlinear data. Several Deep Learning Approaches are available: Numerical Weather Prediction (NWP), needs a highly calculative mathematical equation to gain the present condition of the weather. Quantitative precipitation nowcasting (QPN), is also used for weather prediction. In this article, we have implemented and analyzed the various distinct techniques that are being used in data mining for weather prediction.
Keywords:
Data mining; Deep learning; Weather forecasting; NWP; SVM.

1. Introduction

In daily life, we always try to guess and read the world. Some of the areas of the simple example like today, will rain and that happens after some time [1]. Here we predict by not using any technology or techniques. Now many tools and techniques are available for weather prediction. Weather prediction is a technique that helps in predicting any variation in the atmosphere like rain, cloud cover, snow, wind flow, moisture content, and temperature before these happen. Any variation in these can directly affect the various aspects of living beings. The weather conditions of a specific location can also be predicted by gathering all related multidimensional and non-linear data [2]. Researchers are continuously increasing their knowledge related to atmospheric weather prediction with the help of several weather forecasting tools like satellites, balloons, aircraft, buoys, land stations, radar systems,

Quantitative Precipitation Nowcasting (QPN), Numerical Weather Prediction (NWP), and Data mining. QPN is referred to when high spatial-temporal resolution is required. Numerical Weather Prediction (NWP) for weather analysis and prediction is being used now [3], which is a collection of multi-dimensional and nonlinear equations, called Primitive Equations. The technique popularly being used for the prediction of weather is named the Data mining technique. This data mining technique plays a very

Manuscript received September 5, 2024
Manuscript revised September 20, 2024
https://doi.org/10.22937/IJCSNS.2024.24.9.7

important role in prediction in all fields like industry, science, and society. A huge amount of data could be for analysis with a little bit of effort [4]. It is also a method used to obtain the necessary information by using the raw dataset. It also sets a rule for weather prediction, as per various requirements, rules defined by data mining will vary. This technique is classified as (A) Classification and (B) Clustering. Classification Technique is that type of data extracting technique used to find unknown samples. With the help of the clustering technique, we can easily predict rainfall. The second one is the clustering technique; it groups the object as per the information. This weather prediction technique was found very useful in several applications like environmental impact monitoring, drought spotting, agriculture, pollution dispersal, energy dispersal in the production industry, and so on. Numerous challenges exist now in Numerical weather prediction [5]. The little bit variations in the starting status will result in a large impact on the outcome because the atmosphere is persistent. There are several technical approaches for mining data, especially having: Association methods for data extracting algorithms, classification algorithms methods for the decision tree, clustering algorithms and time series data extracting or mining algorithms, and so on [6]. How can we store, manage, and utilize these large amounts of data, understanding them for deriving a conclusion and a lot of useful information from these data [7]?

2. Literature Survey

Weather forecasting is currently a very popular topic in research these days. In the Neural network approach (NWP), P. Bauer et al. [7] and I. Maqsood et al. [8] have suggested a model that mainly aims to predict and analyze the temperature, relative humidity, and wind speed a day ahead hourly. These models have successfully done a good job in finding seasonal variations while on the second side, it fails in predicting trend and random variations. P. Mohan et al. [9] suggested a way of classification as a Neural network (NN), Support Vector Machine will start using for better results. These suggested techniques are helping in predicting and analyzing rainfall, price forecasting, and harvest production predicting. P. Shivar Anjani et al. [10] analyze the available machine learnings algorithms that are being used in the prediction of weather with the help of data mining. A. A. Taksande et al. [11] utilize the Frequent pattern (FP) growth algorithm technique to gain the decision trees and range to identify the various parameters of the weather as like highest and lowest temperature, rainfall, wind speed, wind moisture content, humidity in the terms in a month and a year. B. Reddyl et al. [12] suggested a forecast of weather with the help of a big data environment with the help of the Hadoop map-reduce method. M. Ramesh et al. [13] suggested Naïve Bayes algorithms and k-method algorithms for the forecasting of weather. It is very useful in Air Traffic, the navy, military, agriculture, forestry, and so on. S. M. Chen et al. [14] suggested a time series model for the fuzzy network system. By using these models, we can easily predict the temperature that working is based on the historical data. K. M. Kwong et al. [15] suggested a neural network that is based on a chaotic oscillator valid for short-term wind forecasting with the help of LIDAR data. S. Afshin et al. [16] suggested a wavelength model for Artificial Neural Networks (ANN) and fuzzy logic that will be very useful in a very long-term rainfall prediction. D. E. Rumelhart et al. [17] A recurrent neural network (RNN) is a category of artificial neural network (ANN) that is used to obtain the prediction of time series. C. Milléo et al. [18] suggested a concept of Numerical weather prediction but the prediction began in 1955 after when the commercial use of programmable computers came into the market. S. Kruizinga et al. [19] suggested a mixed statical technique or the other technique known as a dynamic technique for the forecasting of weather. R. E. Abdel-Aal et al. [20] gave a new concept of perceptron in dynamic modelling. Such techniques have their benefits and limitations and have some challenges like heavy computations, insufficient knowledge of technology, and various such parameters [20, 21].

Table 1. Comparison of Existing DL approaches for weather forecasting

Articles	Outcomes
DNN model for ultra-short-term wind forecasting [22]	Consequences display that attentive choosing of DNN surpasses shallow ones. The model receives a unit input factor and forecast unit specification, and this model is restricted to a few hours of forecasting (<1 hour)
Weather prediction and forecasting	DNN is utilized to forecast rain and temperature change. The scholars utilized four factors as input and

using deep learning methods [23]	forecast unit parameters as output for a specific moment. Prediction capacity of the model of data exactly up to an hour
Short-term local weather forecast analysis operating on dense weather stations by DNN [24]	DNN is utilized to forecast rain and temperature change. The scholars utilized four factors as input and forecast unit parameters as output for a specific moment. Prediction capacity of the model of data exactly up to an hour
Convolutional LSTM network: a machine learning (ML) approach for precipitation type weather analysis and forecasting [25]	Formulated precipitation forecasting as a temporospatial series prediction problem. The suggested design has a unit-input and unit output and can generate a good performance for a time of approx. 6 h
Forecasting and analyzing the weather of Nevada: by a deep learning technique [26]	The model proposed here requires 4 parameters as input and gives one output predicted value as temperature. Outcomes show that the stacked denoising auto-encoder DL model forecasts the exact temperature for a long duration of time
Sequence to sequence weather prediction with LSTM recurrent neural networks [27]	Multi-stacked long short-term memory (LSTM) is being utilized to plot a series of weather having the same length. Utilizes three parameters for input and gives one parameter as output at a time.
Prediction and analysis of weather with the help of multilayer regression algorithms [28]	Multilayer linear regression is much better in providing accuracy in weather prediction and analysis by using 70% as training data and 30% as testing data for algorithms

3. Methodology

The following given below steps will be used for weather analysis and prediction, as shown in Figure 1.

- Setup

Complete data analysis and performance in Anaconda Python Environment 3.6. Using libraries like Pandas, for training purposes, the Python 3.6 environment provided by Google Collaboratory has been used. Libraries such as TensorFlow and Keras have been used.

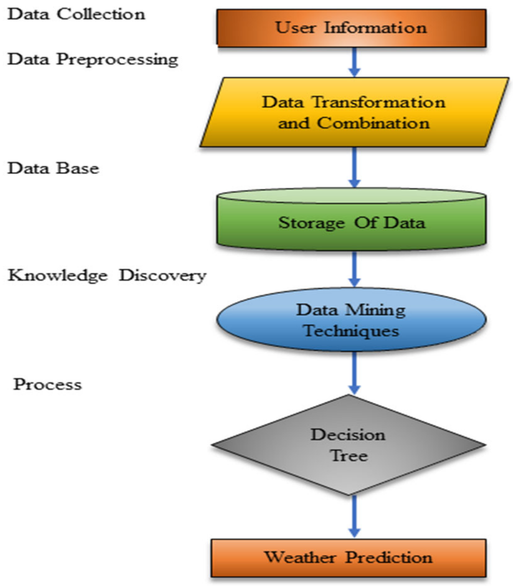

Fig 1: Flow chart of the methodology

- Data pre-processing

Data processing is a method of data mining that involves converting raw data into usable formats. The database contains some missing values. For training a model with the dataset, one should follow the further following techniques.

- Data Cleaning

In the dataset, some of the cells are empty. These empty cells must be filled or re-moved i.e., up sampling or down sampling before feeding this to the various prediction models. First, we assign different numbers to different wind directions and then place them in columns for air indicators. All columns have numerical values in the dew columns point and rain we fill the missing lines with 0 representing dew and rain respectively. We then use line translation to fill in the other columns.

- Feature Selection

Relationships between different clusters of climate data are observed and we can also obtain the covariance matrix that is linearly dependent among unique columns. Top-line columns do not make available the important details in prediction, so they are clear from the database.

- Data Normalization

The goal of standard practice is to convert numerical column values from the dataset to the standard scale, without affecting the difference in price ranges or the loss of any information. Familiarity with assistance in rapid modelling training. We have set up a database outside the temperature range of 0-1.

$$x = \frac{x-\mu}{\sigma} \quad (1)$$

Where,
μ represents mean, σ represents standard deviation and x represents the normalized point.

- Training Model

Multiple weather prediction techniques are available now. These techniques can be used to predict the multiple characteristics of the weather such as rain, pressure, snowfall, etc.

4. Weather Prediction Architecture

Artificial Neural Networks (ANN) and Decision Trees have been applied to analyze weather data, compiled to develop the rules of segregation of use of this Data Mining Techniques approach in analysis and perdition of weather. ANN has received unique attention from various predictive methods in these years [30, 31]. The objective of being popular with neural networks is their ability to supervise learning from complex relationships utilizing indirect activities. This algorithm includes both the series of time and the way back. Climate limits [32] in the study period utilize convenient previously recorded data to predict and analyze near future happening weather events. Objectives for forecasts are those climate variations that have a great influence on our routine lives e.g., variations in size and temperature of the weather, rainfall, evaporation, and wind speed that are going to happen in our near future. These methods are usually very great problem-solving capacity, and flexibility, and are more effective in experimental analysis than mathematical processes. The most used data mining techniques are neural implant networks, object layout, discriminatory analysis, and trees of decision. With this model, we can analyze and predict the temperature (T), rain (R), and air (W) speeds. The way to predict is that only one parameter like some researchers [33] utilized air velocity and rest some of the researchers have utilized wind power to predict [34]. Giving us more accurate forecast data also has many parameters and efficiency.

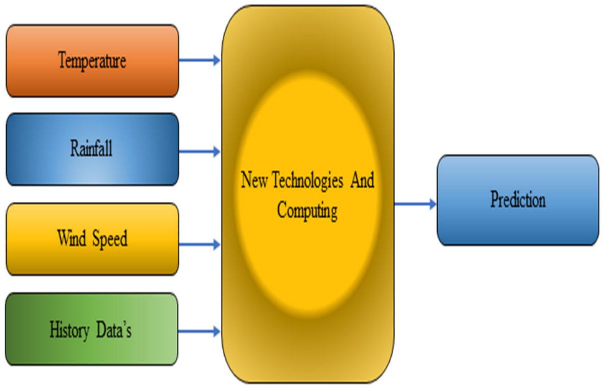

Fig 2: Block representation of weather prediction

A neuron model has mainly three basic elements, known as the perceptron model, (i) Synapses, used to connect the links, each of the synapses had calculated weight/strength itself (ii) additive, summarizing inputs, measured by neuron synapses and (iii) Activation function, reducing the size of neurons release. The standard input relationship is shown in Eq. 1.

$$netj = \sum_{j=1}^{n} WijXi + bj \quad (2)$$

$$Oi = fi\ (neti) \quad (3)$$

Where xi represents node input for the equation, wij represents weights available in-between input node and hidden node, b shows node bias, net equals the adder, and f represents activation function.

A kind of transfer/activation function made variations in the magnitude of the measures in use by weight and space [35]. The construction of the ANN requires determining the count of available connection weights and how the Data flowing through this type of network is made up of a count of layers, the count of every node layer, and the connection between them. The output node counts have been adjusted, depending on the estimated values. The number of input nodes depends on the prevailing issue being ad-dressed, on the modeler's choosing to use domain information. The neurons present in the latent gland are progressively developing, too network output performance in the way the error is checked.

5. Weather Prediction

Weather prediction is a very tough task because of its lengthy calculations. Metrological scientists have been devoted to enhancing the correctness of predictions and forecasts by understanding the physical mechanics and techniques, which is a theory-based approach. Over time areas of research are enhanced then there, and we must manage or explore the data with various sources, and various dimensional and scaled metrological data, it simply means that these data become big Spatio-temporal data. Here, briefly de-scribed the two computing paradigms below:

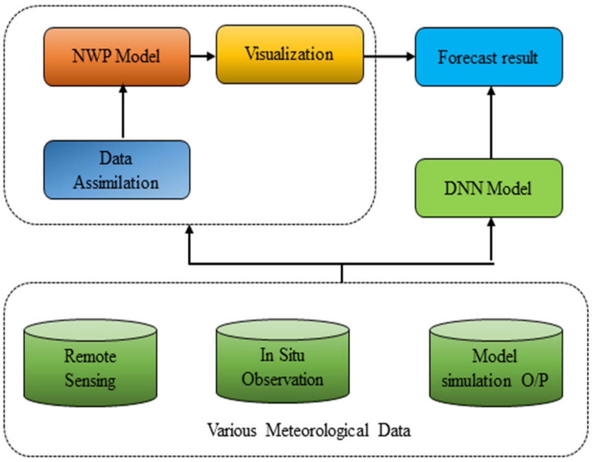

Fig 3. Models used for weather forecasting: theory-driven approach and data-driven approach.

- Numerical weather prediction (NWP)

Usually, the climate conditions near upcoming features can be calculated with the help of combining the dominant partial differential equations which are inspired by the present weather conditions [36]. The non-linear partial differential equation expresses the dynamic, thermodynamics, radiation, and chemical mechanisms of the environment.

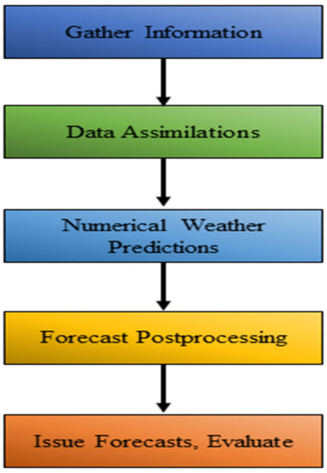

Fig 4: Numerical Weather Prediction Process

Numerical weather prediction predicts the metrological components of the environment like wind speed, temperature, precipitation, the average pressure of the sea level, and so on. The steps involved in NWP are as follows:

(a) Finding the initial observations of the data sets may contain the data obtained from remote sensing, in situ observed information or data, and the simulated data of the NWP.

(b) We must complete all the pre-processing raw data through the available data analysis technique, it also gives control over the quality and guarantees the quality.

(c) Now use these raw- data sets in the atmospheric dynamic model equation for analyzing and predicting.

(d) After successful inputting, we can easily observe the predicted result.

Since all the variables of the equation are meteorological and their value depends on the time change. The simplest form of representation of the NWP equation is as follows:

$$\frac{\Delta A}{\Delta t} = F(A) \quad (4)$$

Where,

ΔA provides the variation for a specific moment in forecast variable in space.

Δt provides the variation in time (for how much time we are going to forecast)

F(A) shows terms that are responsible for changes in the A value. Here we can absorb that any variation in a variable for a specific time range t will equal collective effects cause a change in A.

With the help of initial values, the future value of these meteorological variables with summing up the external forcing variables over time:

$$A^{forecast} = A^{initial} + F(A)\,\Delta t \qquad (5)$$

Where,

F(A) represents the merging of all forcing activities possible.

The horizontal momentum equation,

$$d\vec{V}/dt + f\hat{k} \times \vec{V} = -\nabla \emptyset + \sigma / p_s * \frac{\partial \emptyset}{\partial \sigma} * \nabla p_s + \vec{F} \qquad (6)$$

Continuity Equation,

$$\nabla (p_s \vec{V}) + (\partial(P_s\ \dot{\sigma}))/\partial\sigma + \frac{\partial Ps}{\partial t} = 0 \qquad (7)$$

Thermodynamic energy equation,

$$(1/R) * \frac{d[\sigma * \frac{\partial \emptyset}{\partial \sigma}]}{dt} + (RT/C_p * p) * [p_s\, \dot{\sigma} + \sigma\, \dot{Ps}] = -Q \qquad (8)$$

Hydrostatic equation,

$$\frac{\partial \emptyset}{\partial \sigma} = -RT/\sigma \qquad (9)$$

Surface pressure tendency equation,

$$\frac{\partial Ps}{\partial t} = -\int_0^1 \nabla.[Ps\ \vec{V}]\, d\sigma \qquad (10)$$

And the moisture equation,

$$\frac{\partial [Ps\ q]}{\partial t} + \nabla.\,[p_s\, q\, \vec{V}] + \frac{\partial Ps\ q\ \dot{\sigma}\,]}{\partial \sigma} = p_s\, S \qquad (11)$$

These six equations can be used to get a solution of six hidden parameters i.e., hori-zontal wind velocity V, Surface pressure ps, temperature T, moisture q, geopotential Ø, and sigma velocity σ. The metrological parameters V, ps, T, and q are dependent on time while σ and Ø are known as diagnostic fields,

- Deep learning-based weather prediction (DLWP) approach.

This approach is based on data driven. The actual datasets are inputs to the deep neural network models, that main aim is to obtain the relationship between the input data, and map the feature varies through a huge amount of data. As per the characteristic of the metrological data inputs, we select the perfect DNN techniques in respective data types.

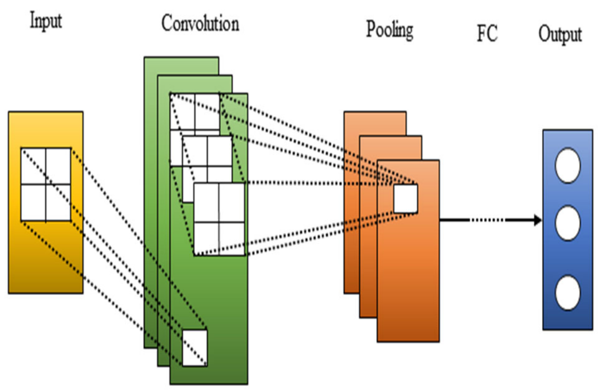

Fig 5 (a): Convolution Neural Network (CNN), pooling, fully connected (FC) layers.

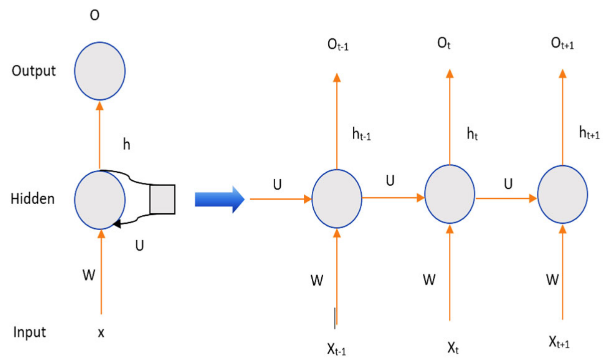

Fig 5 (b): Unfolded Recurrent Neural network (RNN)

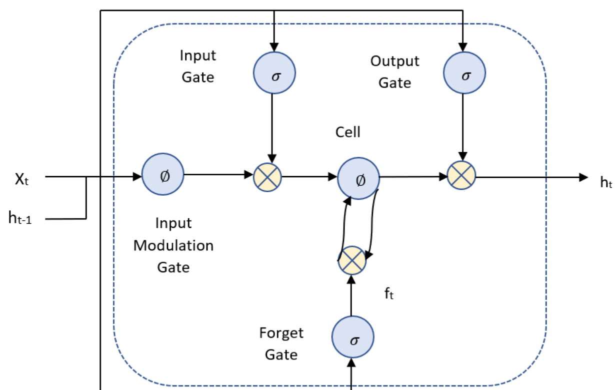

Fig 5 (C): Long short-term memory (LSTM) block

Convolution neural network (CNN) shown in Fig 5(a) is a special type of DNN de-pendent on feature representation, that is mainly created for working on images [37,38,39]. Convolution kernel weights have been shared between the neurons. And the main aim of using the pooling function is to decrease the counts in hyper-parameters in each hidden layer and to avoid the overfitting problem. Thus, CNNs can be applied for weather forecasting through images.

The recurrent neural network (RNN) shown in Fig 5(b) is being used for Time-series problems due to memory function [40]. Here a set of large datasets can't be processed in a single time, but it can process part by part using recurrent networks. It is a very difficult task to train the recurrent networks to die to gradient vanishing and exploding [41].

To address the gradient problem in RNN, long short-term memory (LSTM) shown in Fig 5(c) is proposed [42]. Every LSTM block has one or more than one recurrently joined memory unit and three multiplicative units, named as input gate, forget gate, and output gate [43]. The input gate has the input current as Xt and controls the consideration of cur-rent input. Forget gate, it permits this LSTM model to forget the old memory Ct-1 that be-haves as a key to solve the gradient problem. The last one is the Output gate; it decides to transfer the amount of memory to the hidden state ht. This model of LSTM is very influential for capturing long-term sequences, which is required for long-term weather and cli-mate analysis and simulation [44].

- Machine learning-based weather prediction (MLWP) approach

MLWP may perform relatively much better than the other available options for weather forecasting. Weather forecasting has vastly increased in respect of accuracy and predictability with the help of new emerging technologies and research. Our dataset has divided into training and testing as ¾ and ¼ respectively.

(a) Linear Regression

Linear regression is based on linear and nonlinear functions of machine learning (ML), are used to establish the linear relationship between the target and one or two more predictors. It is also used in finding the relation between the two continuous variables out of them one is an independent variable i.e., predictor and another one is a dependent vari-able i.e., response [45].

Linear regression (LR) is one of the most widely used techniques in ML to find the best model suitable for the distribution of target data, and it has the advantage of identifying multidimensional linear relationships through iterative operations, having an equation of a line in a form of Y=a+bX, where Y is a dependent variable, X is an independent variable, a is the intercept and b is the slope of the line.

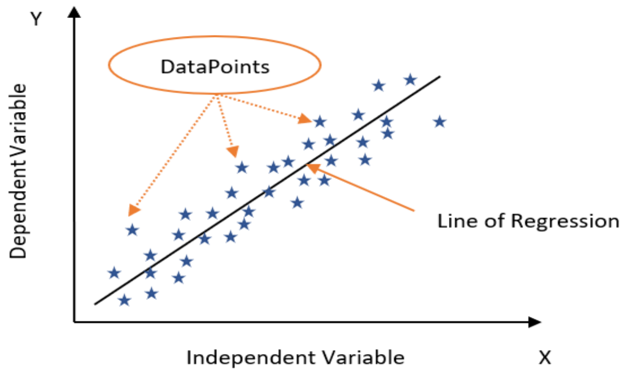

Fig 6: Linear Regression

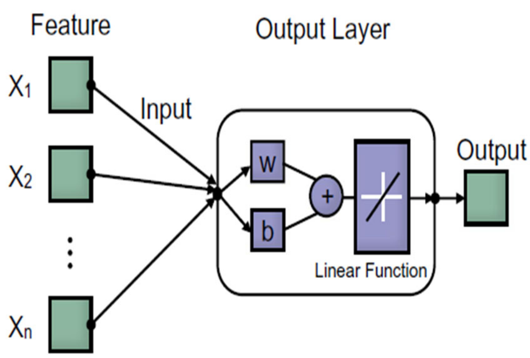

Fig 7: the kernel of Linear Regression [46]

(b) Multiple Linear Regression

The multiple linear regression is given as:

$$\hat{Y} = b0 + b1X1 + b2X2 + \ldots\ldots\ldots\ldots\ldots + bnXn \quad (12)$$

Where Y is equal to the predicted dependent variable i.e., rainfall, X1-Xn are various independent variables like temperature, humidity, rainfall, etc. b1-bn represents regression coefficients. If all the independent variables become zero, then the predicted value will be equal to the value of b0. This linear regression shows a relationship as we can absorb a variation in rainfall (Y) on unit variation independent variables.

(c) Decision Tree

The non-parametric supervised learning approach used for classification and regression applications is the decision tree. It is organized hierarchically and has a root node, branches, internal nodes, and leaf nodes. The root node is present at the highest point in the decision tree. We can handle large amounts of data by using a decision tree. It continues to suffer repeatedly. So do other step-by-step procedures that are required to capture repetition and repetition. Give selection is used to enhance the performance of this decision tree method [47].

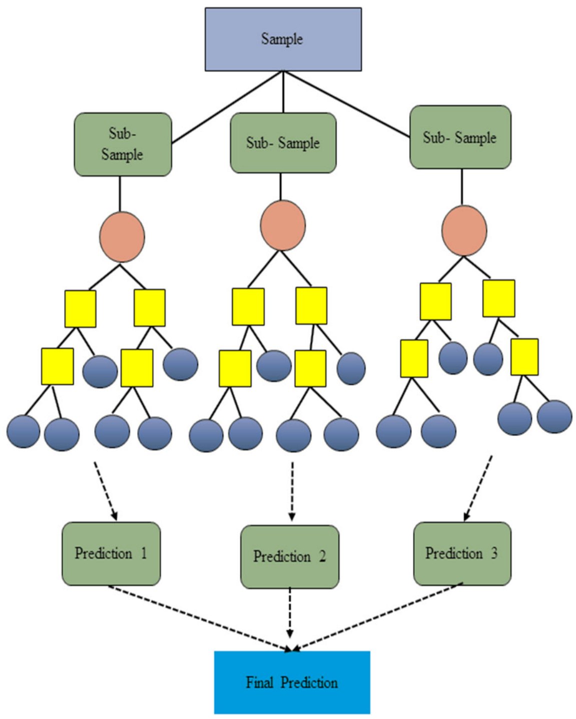

Fig 8: Decision Tree

(d) Support Vector Machine

The SVM model is a special kind of machine learning method dependent on a mathematical learning concept. It is supposed to make available the better separation that creates a complicated border between classes. Separate classes introduce genes on each edge of the available hyperplane. By increasing the genes, we find the greater distance between the hyperplane available there and the samples present there. In subdivided sections, SVM classifies these classes by finding the correct hyper aircraft. As soon as the hyperplane is detected, we must find the support vectors lying on their side [48].

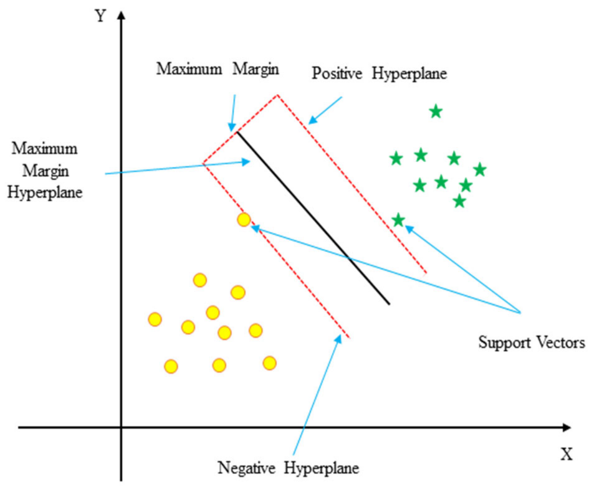

Fig 9: Hyperplane of Support Vector Machine

6. Results

We have considered the dataset named "Austin weather", having file name austin_weather.csv from Kaggle [29] for comparison of weather prediction techniques in this research. This dataset has various features like temperature, humidity, pressure, dew points, visibility, etc. In this dataset, there are some irregularities, so we first go for cleaning and pre-processing steps. We have trained and tested various algorithms on this dataset and obtained certain results.

- Linear Regression

```
The precipitation in inches for the input is: [[1.33868402]]
the precipitation trend graph of rainfall:
```

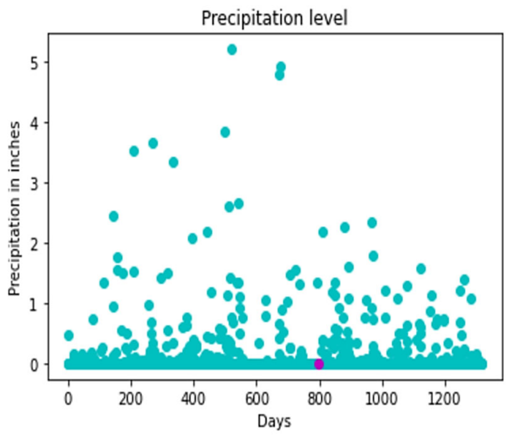

Fig 10 (a): Precipitation (inches) Vs days

On applying the linear regression, we obtained the precipitation level as 1.33868. Below we have obtained the precipitation vs various attributes like humidity, wind speed, temperature, and visibility.

```
Precipitation vs selected attributes graph:
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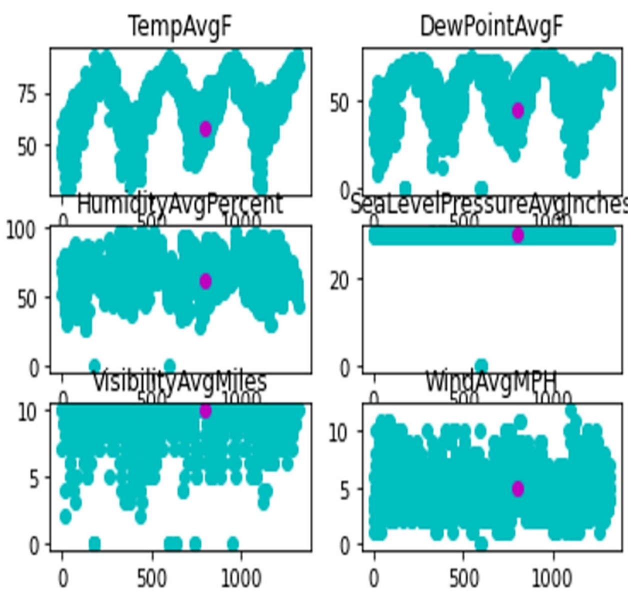

Fig 10 (b): Precipitation (inches) Vs Various attributes

- Multiple Linear Regression

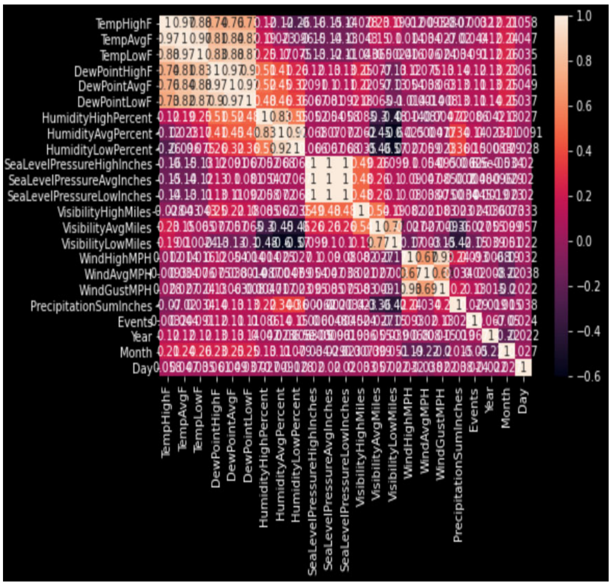

Fig 11 (a): Correlation Matrix for multiple linear regression

Correlation matrices are a way of finding the connection among two or more two continuous variables. For every pair of variables, there is a certain value cross-ponding to them. Here we have established a connection between high, average, and low temperature, High dew factor, low dew factor, average, dew factor, High pressure, low pressure, average pressure, high visibility, low visibility, average visibility, high wind speed, low wind speed, average wind speed, year month and day. Here each value of relationships is found between -0.6 to 1.

Out[17]:

	Actual	Predicted
0	90	90.443163
1	62	62.807290
2	79	78.366271
3	95	94.691647
4	83	83.538401

Fig 11 (b): Actual Vs predicted values.

With the help of this output table, we can easily see the percentage of error from the multiple linear regression and establish a relation between the actual value and the predicted value. By using these actual and predicted values, we have plotted a scatter plot below.

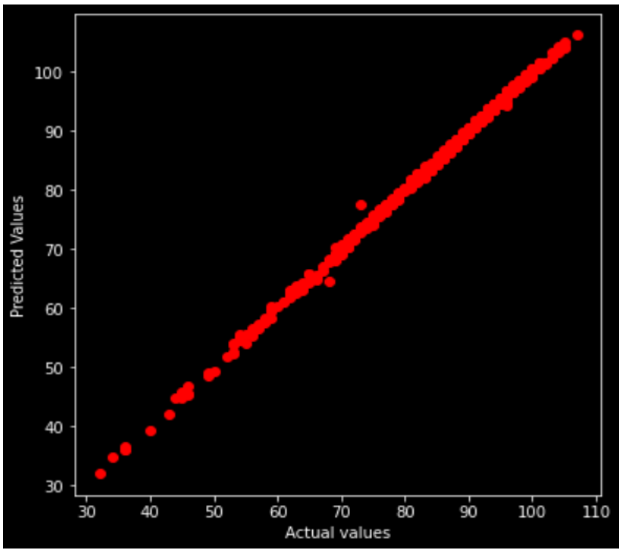

Fig 11 (c): Scatter plotting between actual Vs predicted value.

It is the scatter output plotting of multiple linear regression between actual and predicted values.

```
Accuracy of the model = 0.9972869424803084
Mean absolute error = 0.5
Mean squared error = 0.37
Median absolute error = 0.47
Explain variance score = 1.0
R2 score = 1.0
```

Fig 11(d): Predicted Output for Multiple Linear Regression

We got the accuracy for the model named multiple linear regression as 0.99728.

- Decision Tree

```
Prediction on training data ------------------------
Tree depth: 3 Accuracy: 0.8260869565217391
Tree depth: 4 Accuracy: 0.839262187088274
Tree depth: 5 Accuracy: 0.8458498023715415
Tree depth: 6 Accuracy: 0.855072463768116
Tree depth: 7 Accuracy: 0.8840579710144928

Prediction on test data ----------------------------
Tree depth: 3 Accuracy: 0.8235294117647058
Tree depth: 4 Accuracy: 0.8262032085561497
Tree depth: 5 Accuracy: 0.820855614973262
Tree depth: 6 Accuracy: 0.8235294117647058
Tree depth: 7 Accuracy: 0.8048128342245989
```

Fig 12: Accuracy on training and test data for decision tree

On applying the decision tree algorithm on the same Austin weather dataset, we got 0.88405 accuracies for training the data and 0.82620 accuracies for testing the data.

Here we can absorb that the decision tree is struggling in classifying the fog and thunderstorm, but it is very effective in classifying the clear, rain.

- Support Vector Classifier

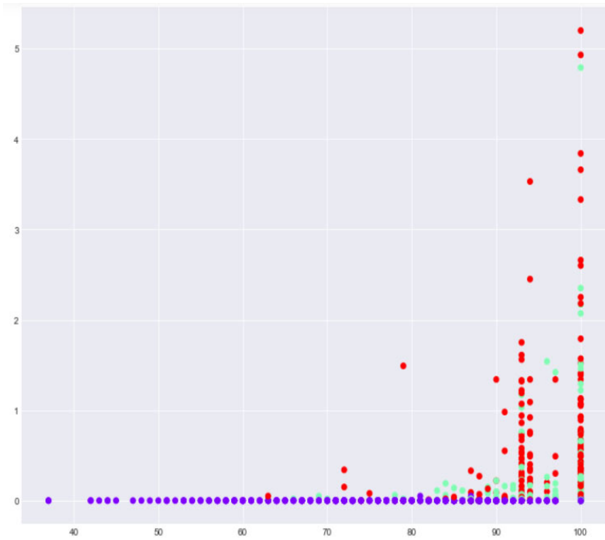

Fig 13 (a): Humidity Vs Precipitation actual

It is the scatter plot of the actual humidity and actual precipitation values. It is measured only for the positive values.

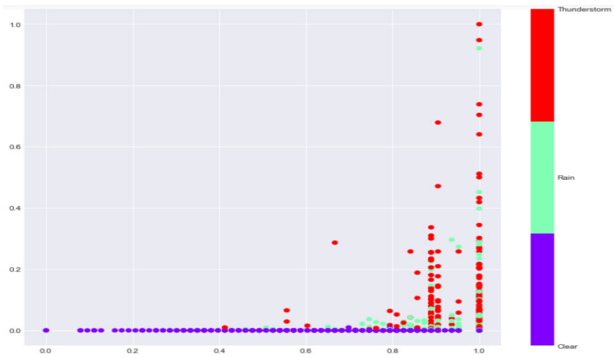

Fig 13 (b): Humidity Vs Precipitation scaled.

It is the scatter plot of the scaled humidity and scaled precipitation values. It is scaled to the value between o and 1. We can say that it is the normalized graph for the actual values.

Out[13]:

	Average	Accuracy	Precision	Recall	F1
0	macro	0.905303	0.847288	0.796030	0.815046
1	micro	0.905303	0.905303	0.905303	0.905303
2	weighted	0.905303	0.899014	0.905303	0.898933

Fig 13 (c): Accuracy with precision value for SVC

On applying the support vector classifier on the same dataset, we obtained an accuracy of 0.905303 for each macro, micro and weighted.

7. Conclusions

This paper will help us in obtaining the best technique for weather forecasting. We have done a comparative study of deep learning techniques that are being used in weather prediction like Linear regression, Multiple linear regression, NWP, Support Vector classifier (SVC), and Decision Tree. These four algorithms are applied to the same data set i.e., the Austin Weather dataset. Out of these algorithms, we have found that a multiple linear regression algorithm is best for weather prediction, and the obtained accuracy level for multiple linear regression is 0.99728 with an error of 0.00272, the accuracy for the decision tree is 0.82620 with an error of 0.1738 and the accuracy for the support vector classifier is 0.905303 with an error of 0.094697. On comparing, we observe that the multiple linear regression algorithm has the highest level of accuracy and the least number of errors. So, multiple linear regression is the best algorithm for weather forecasting.

Acknowledgment

The researchers wish to extend their sincere gratitude to the Deanship of Scientific Research at the Islamic University of Madinah for the support provided to the Post-Publishing Program 2.

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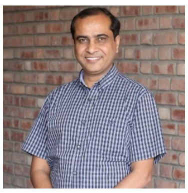

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