Abstract

This paper discusses the use of artificial neural networks in the hurricane trajectory prediction. Some weather phenomena and their relation with neural networks are studied. The data collection and their conversion to fit the needs of neural networks are mentioned, along with the different architectures used in some previous researches. Finally, the results of the hurricane trajectory prediction are discussed along with the future of neural networks in this field.

1. Introduction

Neural networks are inspired by how a neurons system works. A neuron system consists of large numbers of neurons, each of which receives input from other neuron or from the environment. If the total size of the input to the neuron exceeds a threshold the neurons ‘fire’. One feature of the neural networks is that they can be trained. For a hurricane prediction problem one presents various weather readings for a given time $t_0$ as input to the net. The output is taken to be a new location of the hurricane at some time $t_1$ after $t_0$. Then we adjust the behavior of the neuron according to how good or bad the output is.

The prediction of the trajectory that will follow a hurricane has been study for years, but not much is done in terms of neural networks. A hurricane is not an easy environmental event. It involves physics, meteorology, fluids, hydrology and a lot more fields. Scientists have been trying to solve this problem for years and nothing significant has been found.

It is a problem when the meteorologist with a lot of experience predicts a trajectory and four hours later the prediction has been change. Some time results are a disappointment. But, why the models fail in the prediction? Are the models acceptable? Can neural networks be the solution? In the desire to help in the solution of the problem is that this research is done.

First we will assume that the hurricane is a solid that moves in the atmosphere. This means that the fluids, vertical levels, water vapors, etc will not be considered in the early stages of the research. This will simplify the network, since there are a lot of parameters that can affect the prediction. At this point only statistical data will be used.

1.1 Background

Neural networks are inspired by how a nervous system works. A nervous system consists of a large number of neurons, each of which receives inputs from other neurons, or from the environment. If the total size of the input to a neuron exceeds a threshold the neuron will ‘fire’. This output can cause an event outside the nervous system.

One of the features of the neural networks is that they can be trained. For hurricane prediction problem, one presents various hurricane readings for a given time as input to the network. The output is taken to be a new point of displacement of the hurricane. Then the network is adjusted according to the network performance in terms of errors.

Artificial neural networks are abstractions of their natural counterparts. They come in various shapes and sizes, but for time series analysis, two sorts are generally used: recurrent neural networks and multi-layer feed-forward networks. Recurrent nets as the Elman Network, given time and patience, can produce acceptable results. The experiment conducted was done with the feed-forward networks so most part of the theory will develop this architecture. Feed–forward networks are very much simplified abstractions of natural neural nets. Instead of having a tangled mass of neurons, feed-forward networks are arranged in layers.

2. The Hurricane Phenomenon
An intense tropical weather system with a well defined circulation and maximum sustained winds of 74 mph (64 knots) or higher. In the western Pacific, hurricanes are called "typhoons," and similar storms in the Indian Ocean are called "cyclones". Hurricanes are products of the Tropical Ocean and atmosphere. Powered by heat from the sea, they are steered by the easterly trade winds and the temperate waterlines as well as by their own ferocious energy. Around their core, winds grow with great velocity, generating violent seas. Moving ashore, they sweep the ocean inward while spawning tornadoes and producing torrential rains and floods. Each year on average, ten tropical storms (of which six become hurricanes) develop over the Atlantic Ocean, Caribbean Sea, or Gulf of Mexico. Many of these remain over the ocean.

3.0 Experiment with Statistical Data
3.1 Data Collection and Manipulation

Since the experiment was conducted with statistical data only, it needed a source of information. The data was obtained from the Atlantic Tropical Storms Tracked by Year. Here was a database of hurricanes from 1850-2000. For the experiment the most recent hurricanes trajectories was used. From there were used 39 hurricanes, chosen randomly without revising for a common trajectory. With this 39 hurricanes chosen, 34 were use as the training data and 5 for simulations.

This database contained the information of latitude, longitude, wind and pressure. For the experiment only longitude, latitude and pressure were used. After having this information it was decided to normalize the data to the ranges of –1 to 1. This was done having in mind the training procedure, which will be discuss later in the document.

The method of normalization was done with the infinite norm method. This method consists of searching for the highest value of each parameter and dividing the data by this value. The latitude was divided with the highest latitude reported in the 34 hurricanes used for training and so on for each parameter used in the experiment. The variables MaxLat, MaxLon and MaxPr were used for the latitude, longitude and pressure respectively.

Example:

MaxLat = max (max (ALL_LATITUDES));

nLat = nLat/MaxLat;

nLat = Latitudes of each hurricane.

In this way the data was normalize. The advantage of using this method of infinite norm is that we have a unique value for abnormalizing. The first method used was dividing each hurricane parameter by their own norm, but when predicting come to a problem, the doubt was which norm value should be use to restore the data. So in this case the infinite norm method was the most efficient and secure way of normalizing the data.

<table>
<thead>
<tr>
<th>ADV</th>
<th>LAT</th>
<th>LON</th>
<th>WIND</th>
<th>PR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17.4</td>
<td>-84.3</td>
<td>30</td>
<td>1005</td>
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<td>2</td>
<td>18.3</td>
<td>-84.9</td>
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<td>1004</td>
</tr>
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<td>3</td>
<td>19.3</td>
<td>-86.7</td>
<td>35</td>
<td>1003</td>
</tr>
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<td>4</td>
<td>20.6</td>
<td>-85.8</td>
<td>40</td>
<td>1001</td>
</tr>
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<td>-86</td>
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<td>990</td>
</tr>
<tr>
<td>11</td>
<td>29.6</td>
<td>-84.7</td>
<td>60</td>
<td>990</td>
</tr>
</tbody>
</table>

Figure 1 Table of parameters in a hurricane.

After normalizing the data each hurricane was divided into their parameters used in the experiment. Each parameter was convert to a sequence using MATLAB function con2seq (Param). All the hurricanes were added to a same vector creating a vector of 1 row by 1465 columns. This vector was the one fed to the network as prototype and as target with some changes that will be discuss later in the training procedure section.

Since there is not an efficient way of finding the best architecture, the procedure was conducted with trial and error method. In the early stages of the research a recurrent network such as the Elman architecture was considered. Since this network has feedback and it was understood that the next -next step was going to depend on the next step result. The main problem with this architecture is that is time consuming and it needs a considerably big hidden layer for acceptable results. Then adaptive linear predictor architecture was tested. This was used since is most of the time use for predicting functions behavior. Having in mind that the hurricane trajectory prediction in terms of longitude and latitude can be seen as a X vs. Y function prediction. The results with this network were less acceptable than the results of the Elman recurrent architecture. The last network tested was the multi-layer feed-forward. This was selected for all the parameters since 3 networks were created to predict the three different parameters. In the trial and error procedure a variety of number layers, number of neurons, transfer function and training functions were used. The best results of simulation were reached with a 3 layers network. For the latitude prediction the network used was composed of 5 neurons in the first layer with a log sigmoid transfer function, 5 layers in the hidden layer and one neuron in the last layer all with the log sigmoid
transfer function. For the longitude and pressure the network selected was the one presented in figure 3. Which has a 1-10-5-1 with tan sigmoid transfer function.

Figure 2 Network 1-10-5-1 for experiment

3.2 Training Procedure

The main goal was to predict the next step that the hurricane was moving towards. So the network was train in a special way in order to achieve the goal. The architecture as mentioned in the previous section was the multi-layer feed-forward, since this is the most widely used. Once selected the network it was decided to train the network to predict. This was done shifting the targets value one element to the left for each hurricane and setting the last value of each hurricane parameter to zero, since the prototype and the target need to match in this case. In the training procedure the network had to try to converge the actual value of the prototype with its next value. A graphic explanation is provided.

<table>
<thead>
<tr>
<th>Prototype</th>
<th>Lat1</th>
<th>Lat2</th>
<th>Lat3</th>
<th>Lat4</th>
<th>Lat5</th>
<th>Lat6</th>
<th>Lat7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3 Graphical Explanation of relation between prototypes and targets values.

As we can see in Figure 3 the prototype has as target its own second point. Some of the parameters of the network were change. The goal was set to .001; the number of epochs was set to 700 after a procedure of trial and error. Other parameters were let in the defaults value as the learning rate. For training the TRAINLM function was used. The TRAINLM function is very fast in terms of the converging, but it has the disadvantage of been memory consuming. The TRAINDX functions was also used, but it performance was not acceptable comparing it with the TRAINLM. All the networks performance was very good. Having as the worst performance a 0.0213 reported for the pressure network and the best performance was reported to be as low as 0.0045. Which are very good performance results having in mind the procedure of trying to converge an actual value with a next value. Here we present a graphic generated in MATLAB environment of the training procedure of the latitude.

In this experiment the way of training the network was the key point of the experiment since it was show that the training can be a relevant point of having good or not acceptable results in this prediction problem.

3.3 Simulation Procedure

In terms of simulation the procedure was to train the network with 34 out of 39 hurricanes used. Since the other 5 hurricanes were use for testing. For each hurricane that was going to be tested just the first point of each parameter was fed to the network. For the longitude only the first point was used, this giving as output the next point of the longitude. This output was fed again to the network given this point the third prediction and so on up to a maximum of six points. In real life this six points can be approximate to 20 hours depending of the tracking of the hurricane. This procedure was done for all 5 hurricanes for each parameter predicted in the experiment. The way the network was simulated can be defined as a feedback simulation, since the output was fed to the input. In real terms a multi-layer feed-forward network was use, but the simulation did of this architecture a recurrent simulation. The architecture the well-known results of a feed-forward and the dependency of input-output of a recurrent such the Elman networks. Here is presented a figure that explains the way it was simulated.

Figure 4 Feed-Forward with a recurrent simulation

4. Results and Discussion

After a series of testing with the networks used the results got to a point that were considered acceptable, taking in consideration that the predictions are only being done with statistical data. An important point that it was mentioned is the fact that the networks are predicting a maximum of five points ahead of the real location of the hurricane. It was observe from the research done that other computational models most of the time predict only the next point of the location. This prediction is done with a certain error margin. When we see predictions of trajectory we also observe a triangle starting at the hurricane actual location and that this triangle get wider when the trajectory is
predicted with more time ahead. This way of presenting the error is done, because the hurricanes are a very hard event to predict since there are a lot of other atmospheric variables that can change their trajectory. The hurricanes have a very wide number of places to move. The experiment predicts almost 20 hours ahead with the statistical data. Having in mind the way the network was simulated. Remember that is being simulated in a recurrent procedure, so the error of the first simulations can be added to the second one and so on. In terms of values and a differential error percentage the experiment reported in the latitude a range of 0.2466% - 22.4709% of error. This 22.4709% can be observed as a not acceptable result, but this percentage was reported in the last prediction of a no common hurricane trajectory such as Hurricane Lenny. As it was expected in all parameters the last prediction was the least accurate in most of the cases.

In terms of the longitude prediction the error percentages were in most of the cases bigger than the error in the latitude prediction. Here it was reported a range of 4.13% - 8.49% of error percentages. This parameter was also predicted with acceptable. Here it was reported a range of 1.5% - 5.0% of error in the pressure parameter the error percentages were also concluded that no common hurricanes would be in most of the cases.

In general the results were acceptable in all the parameters predicted, since no other atmospheric variable is being considered, also the network was only trained with 34 hurricanes.

5. Conclusions

After testing and evaluating the different networks, it can be said that hurricanes are a very difficult event to track. Statistical data can provide an idea of a possible trajectory of a hurricane, even though the results were as expected, since too much ahead prediction can give very big error margins, as it was demonstrated in the experiment. It was also concluded that no common hurricanes would be difficult to track since not much hurricanes follow a no common path. In general it can be said that the hurricanes trajectory prediction with statistical data can be seen as an X vs. Y function prediction. The model is considerably acceptable and can be improved using more data.

References
