Prediction of CO and NOx Levels in Mexico City Using Associative Models

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Abstract. Artificial Intelligence has been present since more than two decades ago, in the treatment of data concerning the protection of the environment; in particular, various groups of researchers have used genetic algorithms and artificial neural networks in the analysis of data related to the atmospheric sciences and the environment. However, in this kind of applications has been conspicuously absent from the associative models, by virtue of which the classic associative techniques exhibit very low yields. This article presents the results of applying Alpha-Beta associative models in the analysis and prediction of the levels of Carbon Monoxide (CO) and Nitrogen Oxides (NO_x) in Mexico City

Keywords: Associative memories, pollution prediction, atmospheric monitoring.

1 Introduction

In recent years, the care and protection of the environment have become priorities of the majority of the world's governments [1-4] and actively through non-governmental organizations and civil society [5, 6]. The length and breadth of the globe there are specialized agencies on the recording of data corresponding to various environmental variables, whose study and analysis is useful in many cases, in the decision-making related to the preservation of the environment in the local and global. During the 1990s of the 20th century, was established the importance of the paradigm of artificial intelligence, as a valuable assistant, in the tasks of analysis of data related to the atmospheric sciences and the environment [7]. It is noticeable the use of artificial neural networks in the assessment of ecosystems, in the regression of functions of high non-linearity and the prediction of values associated with the variables inherent to the environment [8-11]. Neural networks have evolved over time, and in the year 2002 were created, in the Center for Research in Computing of the National Polytechnic Institute of Mexico, the Alpha-Beta associative models [12, 13] whose efficiency has been shown through different applications in actual databases in different areas of human knowledge [14-40]. In this article, concepts and experimental results obtained by the members of the alpha-beta research group [42] are shown, when applying Alpha-Beta associative models in both CO and NO_x levels included in the databases of the atmospheric monitoring system used in Mexico City (SIMAT) [41]. The rest of the article is organized as follows: sections 2 and 3 describe concisely the SIMAT and the alpha-beta associative models, respectively. Section 4 contains the main proposal of this work, and in section 5 we discuss the experiments and results obtained.

2 SIMAT

Atmospheric Monitoring System of Mexico City (SIMAT, Sistema de Monitoreo ATmosférico) [41] was used to develop this section. Their principal purpose is the measurement of pollutants and meteorological parameters to provide information for the government's decision making related with environment conditions. It is composed of subsystems that capture the information about several pollutants presented in local environment. Below are mentioned the different parts of the SIMAT:

RAMA (Red Automática de Monitoreo Atmosférico, automatic atmospheric monitoring network) makes continuous and permanent ozone measurements (O_3), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter smaller than 10 microns (PM10), particles less than 2.5 micrometers (PM2.5) and hydrogen sulphide (H_2S). All the data is taken hourly from January 1986 to present.

REDMA (Red Manual de Monitoreo Atmosférico, air quality monitoring network) monitors particles suspended and determines the concentration of some elements and components contained in the air. The structure of the database is outlined in table 1, with hourly data taken since January 1986.

REDMET (Red Meteorológica, meteorological network) provides information regarding meteorological parameters in the forecast meteorological and dispersion models. Their main purpose is to analyze the movement of contaminants through the time and allow, in addition, inform the population the UV index, aimed at promoting a healthy exposure to the sun's rays. Table 2 shows some of the parameters provided by REDMET. There are weekly samplings since 1989.

REDDA (Red de Depósito Atmosférico, atmospheric warehouse network) takes samples from wet and dry deposits, whose analysis allows knowing the flow of toxic substances in the atmosphere to the earth's surface and its involvement in the alteration of typical elements of the soil and chemical properties of rain water. REDDA takes samplings 24 hours every six days since 1989.

Table 1. Information provided by REDMA stations.

Pollutant	Abbreviation	Units
Total Suspended Particles	PST	µg/m³
Particles smaller than 10 micrometers	*PM	µg/m³
Particles smaller than 2.5 micrometers	PM2.5	µg/m³
Total Lead suspended particles	PbPS	µg/m³
Lead particles smaller than 10 micrometers	PbPM	µg/m³

Table 2. Information provided by REDMET stations.

Meteorological Parameters	Abbreviation	Units	Stations
Temperature	TMP	°C	15
Relative Humidity	RH	%	15
Wind Direction	WDR	azimuth	15
Wind Velocity (1986 - March 1995)	WSP	miles/hr	15
Wind Velocity (April 1995 - actual)	WSP	m/seg	15

3 Associative Models

The associative models used in this paper, associative memories and neural networks, are based on the Alpha-Beta models [12, 13]. In the learning and recovery phases, minimum and maximum are used. At the same time, there are two binary operations, α and β [12,13]. To be defined, α and β must specify two numerical sets: $A = \{0, 1\}$ and $B = \{0, 1, 2\}$. Table 3 and 4 shows the result of both operations over the A and B sets.

Table 3. α Binary operation

$\alpha : A \times A \to B$		
x	Y	$\alpha(x, y)$
0	0	1
0	1	0
1	0	2
1	1	1

Table 4. β Binary operation

$\beta : B \times A \to A$		
x	y	$\beta(x, y)$
0	0	0
0	1	0
1	0	0
1	1	1
2	0	1
2	1	1

There are 4 matrix operations:

$$\alpha_{\max}: P_{m\times r} \nabla_\alpha Q_{r\times n} = \left\lfloor f_{ij}^{\alpha} \right\rfloor_{m\times n}, \text{ where } f_{ij}^{\alpha} = \bigvee_{k=1}^{r} \alpha\left(p_{ik}, q_{kj}\right) \tag{3.1}$$

$$\beta_{\max}: P_{m\times r} \nabla_\beta Q_{r\times n} = \left\lfloor f_{ij}^{\beta} \right\rfloor_{m\times n}, \text{ where } f_{ij}^{\beta} = \bigvee_{k=1}^{r} \beta\left(p_{ik}, q_{kj}\right) \tag{3.2}$$

$$\alpha_{\min}: P_{m\times r} \Delta_\alpha Q_{r\times n} = \left\lfloor h_{ij}^{\alpha} \right\rfloor_{m\times n}, \text{ where } h_{ij}^{\alpha} = \bigwedge_{k=1}^{r} \alpha\left(p_{ik}, q_{kj}\right) \tag{3.3}$$

$$\beta_{\max}: P_{m\times r} \Delta_\beta Q_{r\times n} = \left\lfloor h_{ij}^{\beta} \right\rfloor_{m\times n}, \text{ where } h_{ij}^{\beta} = \bigwedge_{k=1}^{r} \beta\left(p_{ik}, q_{kj}\right) \tag{3.4}$$

Lemma 3.1 Let $\mathbf{x} \in A^n$ *and* $\mathbf{y} \in A^m$*; then* $\mathbf{y}\ \nabla_\alpha\ \mathbf{x}^t$ *is a matrix of dimension* $m \times n$*, and will also fulfill that:* $\mathbf{y}\ \nabla_\alpha\ \mathbf{x}^t = \mathbf{y}\ \Delta_\alpha\ \mathbf{x}^t$.

Simbol $\boxplus$ is used to represent the operations ∇_α y Δ_α when operates a column vector of dimension n: $\mathbf{y}\ \nabla_\alpha\ \mathbf{x}^t = \mathbf{y} \boxplus \mathbf{x}^t = \mathbf{y}\ \Delta_\alpha\ \mathbf{x}^t$

The ij-nth component of the matrix is $\mathbf{y} \boxplus \mathbf{x}^t$ given by: $[\mathbf{y} \boxplus \mathbf{x}^t]_{ij} = \alpha(y_i, x_j)$

Given an association index μ, the above expression indicates that the ij-nth component of the matrix $\mathbf{y}^\mu \boxplus (\mathbf{x}^\mu)^t$ is expressed in the following manner:

$$[\mathbf{y}^\mu \boxplus (\mathbf{x}^\mu)^t]_{ij} = \alpha\left(y_i^\mu, x_j^\mu\right) \tag{3.5}$$

Lemma 3.2 *Let* $\mathbf{x} \in A^n$ y $\mathbf{P}$ *an array of dimension* $m \times n$*. The operation* $\mathbf{P}_{mxn}\ \nabla_\beta\ \mathbf{x}$ *gives the result of a column vector of dimension m, whose i-nth component tales the following form:*

$$\left(\mathbf{P}_{mxn} \nabla_\beta \mathbf{x}\right)_i = \bigvee_{j=1}^{n} \beta\left(p_{ij}, x_j\right) \tag{3.6}$$

There are two types of Alpha-Beta heteroassociative models: type **V** and type **Λ**. Let look at the type **V**.

Learning phase

Step 1. For each $\mu = 1, 2, ..., p$, from the couple $(\mathbf{x}^\mu, \mathbf{y}^\mu)$ builds the array:

$$[\mathbf{y}^\mu \boxtimes (\mathbf{x}^\mu)^t]_{mxn} \tag{3.7}$$

Step 2. Applying the binary maximum operator $\vee$ to the arrays obtained in step 1:

$$\mathbf{V} = \bigvee_{\mu=1}^{p} \left[\mathbf{y}^{\mu} ?(\mathbf{x}^{\mu})^{t} \right] \tag{3.8}$$

The *ij-nth* entry is given by the following expression:

$$v_{ij} = \bigvee_{\mu=1}^{p} \alpha(y_i^{\mu}, x_j^{\mu}) \tag{3.9}$$

Recovery phase

During this phase, a set of patterns $\mathbf{x}^{\omega}$ are presented, with $\omega \in \{1, 2, ..., p\}$ and the operation Δ_β: $\mathbf{V}\ \Delta_\beta\ \mathbf{x}^{\omega}$ is performed. Given that the dimensions of the matrix $\mathbf{V}$ are m x n and $\mathbf{x}^{\omega}$ is a column vector of dimension n, the result of the previous operation must be a column vector of dimension m, whose i-nth component is:

$$(V \Delta_\beta x^{\varpi})_i = \bigwedge_{j=1}^{n} \beta(v_{ij}, x_j^{\varpi}) \tag{3.10}$$

In the alpha-beta heteroasociative models type Λ, maximums and minimums are exchanged in the expressions above. And for the autoassociative models, the fundamental set is $\{(\mathbf{x}^{\mu}, \mathbf{x}^{\mu}) \mid \mu = 1, 2, ..., p\}$.

In the last five years the applications of the associative models Alpha-Beta in databases of real problems have been heavy and constant. They have been implemented in representative topics of the areas of current knowledge on the border between science and technology, namely: memory architectures [14], mobile robotics [15], software engineering [16], classification algorithms [17-20, 26, 29, 38], BAM [21-24, 32, 34, 40], equalization of industrial colors [25], feature selection [27, 39], image compression [28], Hopfield model [30], binary decision diagrams [31], images in gray levels [33], color images [35], Parkinson's disease [36] and cryptography [37], among others. This work is one of the first incursions of the Alfa-Beta algorithm in environmental issues

4 Proposal

It was proposed the implementation of the Alpha-Beta associative models in the foundations of data from SIMAT subsystems, specifically in the value of CO and NO_x concentrations reported in the database created in the 15 stations. Both CO and NO_x were chosen due to the importance of their impact to the environment. The government of the Federal District of Mexico said that the results of epidemiological studies in Mexico City and other cities with similar problems of pollution indicate that their people are conducive to the early development of chronic respiratory disease because of such type of pollutants.

5 Experiments and results

At the stage of experimentation CO and NO_x data levels were used (both included in the RAMA database). To carry out the experiments, it took the whole of measurement in ppm units (parts per million) of both pollutants obtained in Iztacalco station, sampled every hour for the year 2010. The patterns taken from RAMA database are used in vector form, which were provided to the Alpha-Beta associative model as inputs, being the output data pattern the one that follows 10 input data patterns provided. Thus, the fundamental set was composed of 8749 associations with input patterns of dimension 10 and output patterns of dimension 1. As a set of test took the data obtained by the same monitoring station during the month of February 2011, with an integrated set of 673 associations. The importance of the results presented here lies in the fact that the Alpha-Beta models learned the data generated in the year 2010, and they are able to predict, automatically, the data that would be transferred to some time in one day of 2011. For example, consider the use of Iztacalco station. There was a measurement where the concentration of CO for the February 26th, 2010 was 1.6 ppm, while the Alfa-Beta associative model proposed here predicted by the same day in 2011 at the same time a value of 1.6 ppm too. i.e. the prediction coincided with the real value. On the other hand, on January 25th, 2010, it was recorded 0.022 ppm concentration of NO_x, while our system predicted a concentration of 0.018 ppm, which means a difference ppm of NO_x. In some cases during the same month, differences were in excess. For example, on February 23rd, 2011, the recorded concentration was of 0,040 ppm of NO_x, while our system predicted a concentration of 0,053 ppm, which means a difference of +0.013 ppm. As numerical metric performance, the ingrain square root mean square error (RMSE) is used, which is one of the performance measures more used in forecasting intelligent, and is according to the equation 5.1. On the other hand, to describe how much underestimates or overestimated the situation the model, bias was used, which is calculated in accordance with the equation 5.2. RMSE and bias values are presented in Table 5. For both equations, P_i is the i-nth value predicted and O_i is the i-th original value.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2} \quad (5.1)$$

$$Bias = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i) \quad (5.2)$$

Figure 1 and 2 shows the graphs containing the results derived from the application of the associative models reported in section 3, applied to the information provided by SIMAT. A very close follow between the curves in both figures can be observed, which indicates the prediction performance reached by the application of the associative models.

Table 5. Performance measurement values used in the prediction of pollutants.

Pollutant	RMSE	Bias
CO	0.00414	-1.8
NO_x	0.000887	-0.546

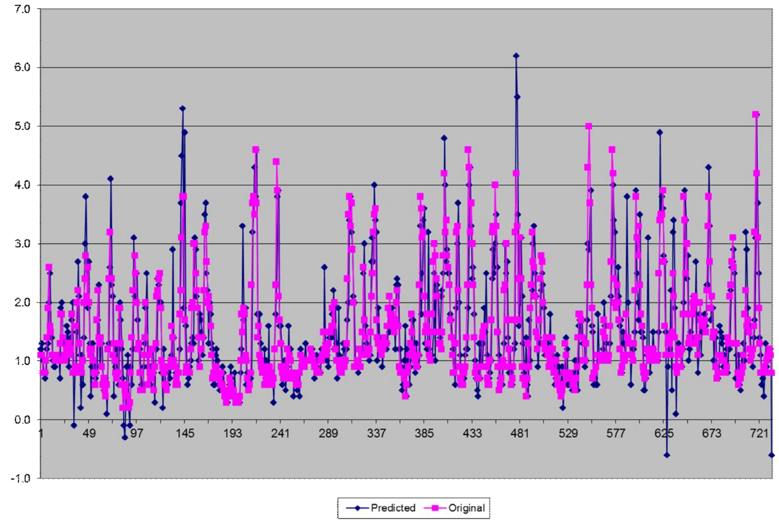

Fig. 1. CO observed in 2010 and predicted in 2011.

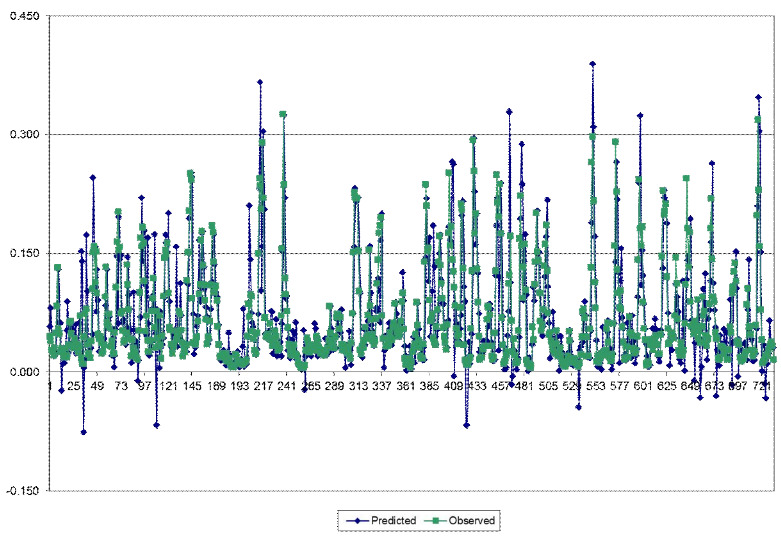

Fig. 2. NO_x emissions observed in 2010 and predicted in 2011.

Acknowledgments. The authors gratefully acknowledge the Instituto Politécnico Nacional (Secretaría Académica, COFAA, SIP, and CIC), CONACyT, SNI, and ICyTDF (grants PIUTE10-77 and PICSO10-85) for their support to develop this work.

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