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► **To cite this version:**

Amadeo Argüelles, Cornelio Yáñez, Itzamá López, Oscar Camacho. Prediction of CO and NO_x Levels in Mexico City Using Associative Models. 12th Engineering Applications of Neural Networks (EANN 2011) and 7th Artificial Intelligence Applications and Innovations (AIAI), Sep 2011, Corfu, Greece. pp.313-322, 10.1007/978-3-642-23960-1_38 . hal-01571491

HAL Id: hal-01571491

<https://inria.hal.science/hal-01571491>

Submitted on 2 Aug 2017

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Prediction of CO and NO_x 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 (O₃), sulfur dioxide (SO₂), 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 (H₂S). 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	$\mu\text{g}/\text{m}^3$
Particles smaller than 10 micrometers	*PM	$\mu\text{g}/\text{m}^3$
Particles smaller than 2.5 micrometers	PM2.5	$\mu\text{g}/\text{m}^3$
Total Lead suspended particles	PbPS	$\mu\text{g}/\text{m}^3$
Lead particles smaller than 10 micrometers	PbPM	$\mu\text{g}/\text{m}^3$

Table 2. Information provided by REDMET stations.

Meteorological Parameters	Abbreviation	Units	Stations
Temperature	TMP	$^{\circ}\text{C}$	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

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

Table 4. β Binary operation

$\beta : B \times A \rightarrow A$		
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:

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

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

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

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

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:

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

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

$$(\mathbf{P}_{m \times n} \nabla_{\beta} \mathbf{x})_i = \vee_{j=1}^n \beta(p_{ij}, x_j) \quad (3.6)$$

There are two types of Alpha-Beta heteroassociative models: type \mathbf{V} and type $\mathbf{\Lambda}$. Let look at the type \mathbf{V} .

Learning phase

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

$$[\mathbf{y}^{\mu} \boxtimes (\mathbf{x}^{\mu})^t]_{m \times n} \quad (3.7)$$

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

$$\mathbf{V} = \bigvee_{\mu=1}^p [\mathbf{y}^{\mu} \wedge (\mathbf{x}^{\mu})^t] \quad (3.8)$$

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

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

Recovery phase

During this phase, a set of patterns \mathbf{x}^{ω} are presented, with $\omega \in \{1, 2, \dots, p\}$ and the operation Δ_{β} : $\mathbf{V} \Delta_{\beta} \mathbf{x}^{\omega}$ is performed. Given that the dimensions of the matrix \mathbf{V} are $m \times n$ and \mathbf{x}^{ω} 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:

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

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

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

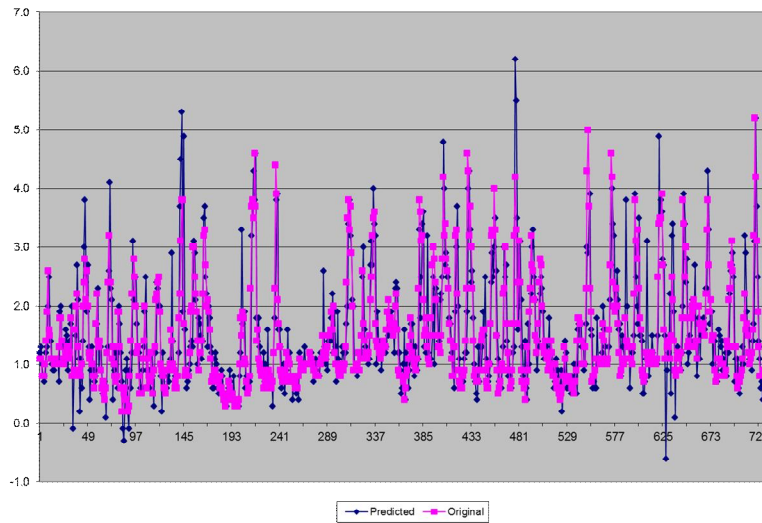


Fig. 1. CO observed in 2010 and predicted in 2011.

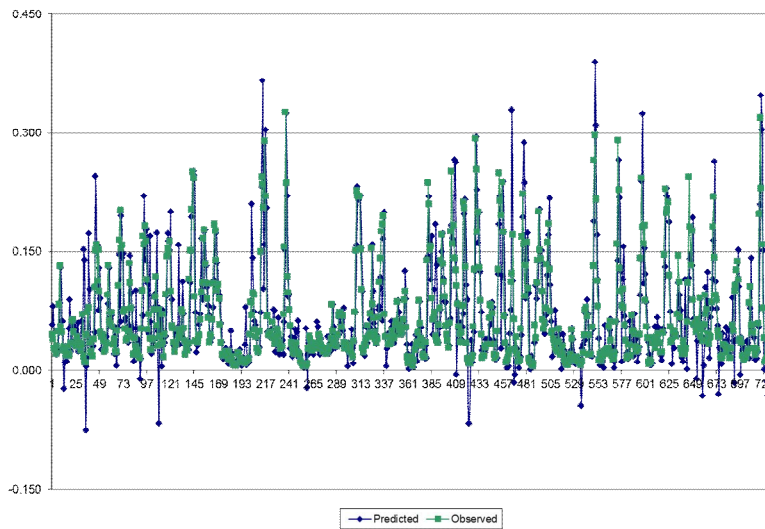


Fig. 2. NO_x emissions observed in 2010 and predicted in 2011.

Acknowledgments. The authors gratefully acknowledge the Instituto Politécnico Nacional (Secretaría Académica, COFAA, SIP, and CIC), CONACyT, SNI, and ICyTDF (grants PIUTE10-77 and PICO10-85) for their support to develop this work.

References

1. Secretaría de Comercio y Fomento Industrial. PROTECCIÓN AL AMBIENTE - CONTAMINACIÓN DEL SUELO - RESIDUOS SÓLIDOS MUNICIPALES - DETERMINACIÓN DE AZUFRE, Norma Mexicana NMX-AA-092-1984, México (1984)
2. Secretaría de Comercio y Fomento Industrial. PROTECCIÓN AL AMBIENTE - CONTAMINACIÓN ATMOSFÉRICA - DETERMINACIÓN DE NEBLINA DE ACIDO FOSFÓRICO EN LOS GASES QUE FLUYEN POR UN CONDUCTO, Norma Mexicana NMX-AA-090-1986, México (1986)
3. Secretaría de Comercio y Fomento Industrial. POTABILIZACION DEL AGUA PARA USO Y CONSUMO HUMANO-POLIAMINAS-ESPECIFICACIONES Y METODOS DE PRUEBA, Norma Mexicana NMX-AA-135-SCFI-2007, México (2007)
4. <http://mediambient.gencat.net/cat>. Web del Departamento de Medio Ambiente y Vivienda de la Generalitat de Cataluña (2007)
5. Toepfer, Klaus et.al. Aliados Naturales: El Programa de las Naciones Unidas para el Medio Ambiente (PNUMA) y la sociedad civil, UNEP-United Nations Foundation (2004)
6. Hisas, Liliana et.al. A Guide to the Global Environmental Facility (GEF) for NGOs, UNEP-United Nations Foundation (2005)
7. Hart, J., Hunt, I., and Shankaraman, V. Environmental Management Systems - a Role for AI?, Proc. Binding Environmental Sciences and Artificial Intelligence BESAI'98, pp. 1-9, Brighton, UK (1998)
8. Gardner, M.W., and Dorling, S.R. Artificial neural networks (the multilayer perceptron)--a review of applications in the atmospheric sciences, Atmospheric Environment, Vol. 32, No. 14/15, pp. 2627-2636 (1998)
9. Nunnari, G., Nucifora, A.F.M., and Randieri, C. The application of neural techniques to the modelling of time-series of atmospheric pollution data, Ecological Modelling 111, pp. 187-205 (1998)
10. Spellman, G. An application of artificial neural networks to the prediction of surface ozone, Applied Geography 19, pp. 123-136 (1999)
11. Corchado, J.M., and Fyfe, C. Unsupervised Neural Network for Temperature Forecasting, Artificial Intelligence in Engineering Vol. 13, No. 4, pp. 351-357 (1999)
12. Yáñez Márquez, Cornelio. Memorias Asociativas basadas en Relaciones de Orden y Operadores Binarios, Tesis Doctoral del Doctorado en Ciencias de la Computación, Centro de Investigación en Computación del Instituto Politécnico Nacional, México (2002)
13. Yáñez Márquez, C. & Díaz-de-León Santiago, J.L. Memorias Asociativas Basadas en Relaciones de Orden y Operaciones Binarias, Computación y Sistemas, Vol. 6, No. 4, México, pp. 300-311. ISSN 1405-5546 (2003)
14. Camacho Nieto, O., Villa Vargas, L.A., Díaz de León Santiago, J.L. & Yáñez Márquez, C. Diseño de Sistemas de Memoria Cache de Alto Rendimiento aplicando Algoritmos de Acceso Seudo-Especulativo, Computación y Sistemas, Vol. 7, No. 2, México, pp. 130-147. ISSN 1405-5546 (2003)
15. Yáñez-Márquez, Cornelio, Díaz de León-S., Juan L. & Camacho-N., Oscar. Un sistema inteligente para telepresencia de robots móviles, en Proc. de la Décimoquinta Reunión de Otoño de Comunicaciones, Computación, Electrónica y Exposición Industrial "La Convergencia de Voz, Datos y Video", ROC&C'2004, IEEE Sección México, Acapulco, Guerrero, México (2004)
16. López-Martín, C., Leboeuf-Pasquier, J., Yáñez-Márquez, C. & Gutiérrez-Tornés, A. Software Development Effort Estimation Using Fuzzy Logic: A Case Study, en IEEE Computer Society, Proc. Sixth Mexican International Conference on Computer Science. ISBN: 0-7695-2454-0, ISSN: 1550 4069, pp. 113-120 (2005)

17. Flores Carapia, R. & Yáñez Márquez, C. Minkowski's Metrics-Based Classifier Algorithm: A Comparative Study, en Memoria del XIV Congreso Internacional de Computación CIC'2005, celebrado en las instalaciones del Instituto Politécnico Nacional, México, del 7 al 9 de septiembre de 2005. ISBN: 970-36-0267-3, pp. 304-315 (2005).
18. Muñoz Torija, J.M. & Yáñez Márquez, C. Un Estudio Comparativo del Perceptron y el Clasificador Euclideano, en Memoria del XIV Congreso Internacional de Computación CIC'2005, celebrado en las instalaciones del Instituto Politécnico Nacional, México, del 7 al 9 de septiembre de 2005. ISBN: 970-36-0267-3, pp. 316-326 (2005)
19. Sánchez-Garfias, F.A., Díaz-de-León Santiago, J.L & Yáñez-Márquez, C. A new theoretical framework for the Steinbuch's Lernmatrix, en Proc. Optics & Photonics 2005, Conference 5916 Mathematical Methods in Pattern and Image Analysis, organizado por la SPIE (International Society for Optical Engineering), San Diego, CA., del 31 de julio al 4 de agosto de 2005. ISBN: 0-8194-5921-6, ISSN: 0277-786X, pp. (59160)N1-N9 (2005)
20. Argüelles, A.J., Yáñez, C., Díaz-de-León Santiago, J.L & Camacho, O. Pattern recognition and classification using weightless neural networks and Steinbuch Lernmatrix, en Proc. Optics & Photonics 2005, Conference 5916 Mathematical Methods in Pattern and Image Analysis, organizado por la SPIE (International Society for Optical Engineering), San Diego, CA., del 31 de julio al 4 de agosto de 2005. ISBN: 0-8194-5921-6, ISSN: 0277-786X, pp. (59160)P1-P8 (2005)
21. Acevedo-Mosqueda, M.E. & Yáñez-Márquez, C. Alpha-Beta Bidirectional Associative Memories, Computación y Sistemas (Revista Iberoamericana de Computación incluida en el Índice de CONACyT), Vol. 10, No. 1, México, pp. 82-90. ISSN: 1405-5546 (2006)
22. Acevedo-Mosqueda, M.E., Yáñez-Márquez, C. & López-Yáñez, I. Alpha-Beta Bidirectional Associative Memories, IJCIR International Journal of Computational Intelligence Research, Vol. 3, No. 1, pp. 105-110. ISSN: 0973-1873 (2006)
23. Acevedo-Mosqueda, M.E., Yáñez-Márquez, C., & López-Yáñez, I. Complexity of Alpha-Beta Bidirectional Associative Memories, Lecture Notes in Computer Science, LNCS 4293, Springer-Verlag Berlin Heidelberg, pp. 357-366. ISSN: 0302-9743 (2006)
24. Acevedo-Mosqueda, M.E., Yáñez-Márquez, C. & López-Yáñez, I. Alpha-Beta Bidirectional Associative Memories Based Translator, IJCSNS International Journal of Computer Science and Network Security, Vol. 6, No. 5A, pp. 190-194. ISSN: 1738-7906 (2006)
25. Yáñez-Márquez, C., Felipe-Riverón, E.M., López-Yáñez, I. & Flores-Carapia, R. A Novel Approach to Automatic Color Matching, Lecture Notes in Computer Science, LNCS 4225, Springer-Verlag Berlin Heidelberg, pp. 529-538. ISSN: 0302-9743 (2006)
26. Román-Godínez, I., López-Yáñez, I., & Yáñez-Márquez, C. A New Classifier Based on Associative Memories, IEEE Computer Society, Proc. 15th International Conference on Computing, CIC 2006. ISBN: 0-7695-2708-6, pp. 55-59 (2006)
27. Aldape-Pérez, M., Yáñez-Márquez, C. & López -Leyva, L.O. Feature Selection using a Hybrid Associative Classifier with Masking Technique, en IEEE Computer Society, Proc. Fifth Mexican International Conference on Artificial Intelligence, MICA 2006. ISBN: 0-7695-2722-1, pp. 151-160 (2006)
28. Guzmán, E., Pogrebnyak, O. & Yáñez-Márquez, C. Image Compression Algorithm Based on Morphological Associative Memories, Lecture Notes in Computer Science, LNCS 4225, Springer-Verlag Berlin Heidelberg pp. 519-528. ISSN: 0302-9743 (2006)
29. Aldape-Pérez, M., Yáñez-Márquez, C. & López -Leyva, L.O. Optimized Implementation of a Pattern Classifier using Feature Set Reduction, Research in Computing Science, Vol. 24, Special issue: Control, Virtual Instrumentation and Digital Systems, IPN México, pp. 11-20. ISSN 1870-4069 (2006)
30. Catalán-Salgado, E.A. & Yáñez-Márquez, C. Non-Iterative Hopfield Model, en IEEE Computer Society, Proc. Electronics, Robotics, and Automotive Mechanics Conference,

- CERMA 2006, Vol. II. ISBN: 0-7695-2569-5, ISSN/Library of Congress Number 2006921349, pp. 137-144 (2006)
31. López-Yáñez, I., & Yáñez-Márquez, C. Using Binary Decision Diagrams to Efficiently Represent Alpha-Beta Associative Memories, en IEEE Computer Society, Proc. Electronics, Robotics, and Automotive Mechanics Conference, CERMA 2006, Vol. I. ISBN: 0-7695-2569-5, ISSN/Library of Congress Number 2006921349, pp. 172-177 (2006)
 32. Acevedo-Mosqueda, M.E., Yáñez-Márquez, C., & López-Yáñez, I. A New Model of BAM: Alpha-Beta Bidirectional Associative Memories, Lecture Notes in Computer Science, LNCS 4263, Springer-Verlag Berlin Heidelberg pp. 286-295. ISSN: 0302-9743 (2006)
 33. Yáñez-Márquez, C., Sánchez-Fernández, L. P. & López-Yáñez, I. Alpha-Beta Associative Memories for Gray Level Patterns, Lecture Notes in Computer Science, LNCS 3971, Springer-Verlag Berlin Heidelberg, pp. 818-823. ISSN: 0302-9743 (2006)
 34. Acevedo-Mosqueda, M.E., Yáñez-Márquez, C., & López-Yáñez, I. A New Model of BAM: Alpha-Beta Bidirectional Associative Memories, Journal of Computers, Vol. 2, No. 4, Academy Publisher, pp. 49-56. ISSN: 1796-203X
 35. Yáñez-Márquez, C., Cruz-Meza, M.E., Sánchez-Garfias, F.A. & López-Yáñez, I. Using Alpha-Beta Associative Memories to Learn and Recall RGB Images, Lecture Notes in Computer Science, LNCS 4493, Springer-Verlag Berlin Heidelberg, pp. 828-833. ISBN: 978-3-540-72394-3 (2007)
 36. Ortiz-Flores, V.H., Yáñez-Márquez, C., Kuri, A., Miranda, R., Cabrera, A. & Chairez, I. Non parametric identifier for Parkinson's disease dynamics by fuzzy-genetic controller, Proc. of the 18th International Conference MODELLING AND SIMULATION, May 30 – June 1 2007, Montreal, Quebec, Canada, pp. 422-427. ISBN: 978-0-88986-663-8 (2007)
 37. Silva-García, V.M., Yáñez-Márquez, C. & Díaz de León-Santiago, J.L. Bijective Function with Domain in N and Image in the Set of Permutations: An Application to Cryptography, IJCSNS International Journal of Computer Science and Network Security, Vol. 7, No. 4, pp. 117-124. ISSN: 1738-7906 (2007)
 38. Román-Godínez, I., López-Yáñez, I., & Yáñez-Márquez, C. Perfect Recall on the Lernmatrix, Lecture Notes in Computer Science, LNCS 4492, Springer-Verlag Berlin Heidelberg, pp. 835-841. ISBN: 978-3-540-72392-9 (2007)
 39. Aldape-Pérez, M., Yáñez-Márquez, C., & Argüelles-Cruz, A.J. Optimized Associative Memories for Feature Selection, Lecture Notes in Computer Science, LNCS 4477, Springer-Verlag Berlin Heidelberg, pp. 435-442. ISBN: 978-3-540-72846-7 (2007)
 40. Acevedo-Mosqueda, M.E., Yáñez-Márquez, C., & López-Yáñez, I. Alpha-Beta Bidirectional Associative Memories: Theory and Applications, Neural Processing Letters, Vol. 26, No. 1, August 2007, Springer-Verlag Berlin Heidelberg, pp. 1-40. ISSN: 1370-4621 (2007)
 41. Sistema de monitoreo atmosférico de la Ciudad de México <http://www.sma.df.gob.mx/simat/>
 42. <http://www.cornelio.org.mx>