Research Article

MIMO System Reduction Using Modified Pole Clustering and Genetic Algorithm

C. B. Vishwakarma[1] and R. Prasad[2]

[1] *Faculty of Engineering and Technology, Gurukul Kangri University, Haridwar 249-404, India*
[2] *Department of Electrical Engineering, Indian Institute of Technology, Roorkee 247-667, India*

Correspondence should be addressed to C. B. Vishwakarma, cbv_gkv@yahoo.co.in

A new mixed method for reducing the order of the large-scale linear dynamic multi-input-multi-output (MIMO) systems has been presented. In this method, the common denominator polynomial of the reduced-order transfer function matrix is synthesized by using modified pole clustering while the coefficients of the numerator elements are computed by minimizing the integral square error between the time responses of the original and reduced system element using Genetic Algorithm. The modified pole clustering generates more dominant cluster centres than cluster centres obtained by pole clustering technique already available in literature. The proposed algorithm is computer-oriented and comparable in quality. This method guarantees stability of the reduced model if the original high-order system is stable. The algorithm of the proposed method is illustrated with the help of an example and the results are compared with the other well-known reduction techniques.

1. Introduction

Every physical system can be translated into mathematical model. The mathematical procedure of system modeling often leads to comprehensive description of a process in the form of high-order differential equations which are difficult to use either for analysis or controller synthesis. It is, therefore, useful, and sometimes necessary, to find the possibility of finding some equations of the same type but of lower order that may be considered to adequately reflect the dominant characteristics of the system under consideration. Some of the reasons for using reduced-order models of high-order linear systems could be as follows:

(i) to have a better understanding of the system,

(ii) to reduce computational complexity,

(iii) to reduce hardware complexity,

(iv) to make feasible controller design.

Several reduction methods are available in literature for reducing the order of large-scale linear MIMO systems in frequency domain [1–4]. Further, some mixed methods have been suggested by combining the algorithm of two different reduction methods [5–7]. In spite of having several reduction methods, none always gives the satisfactory results for all the systems.

The optimization-based reduced-order modeling has already been suggested in the work [8–10] in which the numerator coefficients are computed by minimizing the integral square error (ISE) between the step responses of the original and the reduced system while the denominator polynomial is obtained by using existing order-reduction technique.

The Genetic Algorithm (GA) is a popular optimization technique in the science and engineering nowadays. This is based on the process of Darwin 's Theory of Evolution. By starting with a set of potential solutions and changing them during several iterations, the GA hopes to converge on the most "fit" solution. The process begins with a set of potential solutions or chromosomes (usually in the form of bit strings) that are randomly generated or selected. The entire set of these chromosomes comprises a population. The chromosomes evolve during several iterations or generations. New generations (offspring) are generated using

the crossover and mutation technique. Crossover involves splitting two chromosomes and then combining one half of each chromosome with the other pair. Mutation involves flipping a single bit of a chromosome. The chromosomes are then evaluated using a certain fitness criteria and the best ones are kept while the others are discarded. This process repeats until one chromosome has the best fitness and thus is taken as the best solution of the problem [11].

The authors suggested a modified pole clustering based on the concept of the clustering technique [12, 13] in which clusters of the poles of the original high-order system are formed and then each cluster is replaced by its cluster centre by using inverse distance measure criterion. The modified pole clustering technique generates more dominant cluster centre than the cluster centre obtained by authors [12, 13].

In the present study, the authors proposed a new mixed method for reducing the order of the linear MIMO systems in which the common denominator polynomial of the reduced system is obtained by using modified pole clustering while the coefficients of the numerator element of the reduced model are computed by using GA.

2. Reduction Method

Let the nth-order transfer function matrix of the high-order original system having "p" inputs and "q" outputs be

$$[G(s)] = \frac{1}{D_n(s)} \begin{bmatrix} a_{11}(s) & a_{12}(s) & \cdots & a_{1p}(s) \\ a_{21}(s) & a_{22}(s) & \cdots & a_{2p}(s) \\ \vdots & \vdots & \vdots & \vdots \\ a_{q1}(s) & a_{q2}(s) & \cdots & a_{qp}(s) \end{bmatrix}, \quad (1)$$

or let $[G(s)] = [g_{ij}(s)]$, $i = 1, 2, \ldots, q$; $j = 1, 2, \ldots, p$ be a $q \times p$ transfer matrix.

The general form of $g_{ij}(s)$ can be taken as

$$g_{ij}(s) = \frac{a_{ij}(s)}{D_n(s)} = \frac{a_0 + a_1 s + \cdots + a_{n-1} s^{n-1}}{b_0 + b_1 s + \cdots + b_n s^n}, \quad (2)$$

where $i = 1, 2, \ldots, q$; $j = 1, 2, \ldots, p$.

Let the reduced transfer function matrix of the kth-order having "p" inputs and "q" outputs to be synthesized as

$$[R_k(s)] = \frac{1}{D_k(s)} \begin{bmatrix} c_{11}(s) & c_{12}(s) & \cdots & c_{1p}(s) \\ c_{21}(s) & c_{22}(s) & \cdots & c_{2p}(s) \\ \vdots & \vdots & \vdots & \vdots \\ c_{q1}(s) & c_{q2}(s) & \cdots & c_{qp}(s) \end{bmatrix}, \quad (3)$$

or let $[R_k(s)] = [r_{ij}(s)]$, $i = 1, 2, \ldots, q$; $j = 1, 2, \ldots, p$ be a $q \times p$ transfer matrix.

The general form of $r_{ij}(s)$ can be taken as

$$r_{ij}(s) = \frac{c_{ij}(s)}{D_k(s)} = \frac{c_0 + c_1 s + \cdots + c_{k-1} s^{k-1}}{d_0 + d_1 s + \cdots + d_k s^k}, \quad (4)$$

where $i = 1, 2, \ldots, q$; $j = 1, 2, \ldots, p$.

The objective of this paper is to realize a reduced transfer matrix of the kth-order in the form of (3) from the original high-order transfer matrix (1) such that it retains the important features of the original high-order system $[G(s)]$.

Further, the reduction procedure consists of the following two steps.

Step 1. Determination of the common denominator polynomial $D_k(s)$ for the reduced transfer matrix using modified pole clustering technique.

The brief algorithm for realizing the denominator polynomial by using the modified pole clustering is as follows.

Let there be r real poles in the ith cluster: $p_1, p_2, \ldots, p_r$, where $|p_1| < |p_2| \cdots < |p_r|$, and then modified cluster centre p_{ei} can be obtained by using the algorithm of the modified pole clustering suggested in this paper.

Let m pairs of complex conjugate poles in a jth cluster be

$$[(\alpha_1 \pm j\beta_1), (\alpha_2 \pm j\beta_2), \ldots, (\alpha_m \pm j\beta_m)], \quad (5)$$

where $|\alpha_1| < |\alpha_2| \cdots < |\alpha_m|$.

Now using the same algorithm separately for real and imaginary parts of the complex conjugate poles, the modified cluster centre is obtained as

$$\Phi_{ej} = A_{ej} \pm jB_{ej}, \quad (6)$$

where $\overset{*}{\Phi}_{ej} = A_{ej} + jB_{ej}$ and $\overset{\circ}{\Phi}_{ej} = A_{ej} - jB_{ej}$.

An interactive computer programme has been developed that automatically finds the modified cluster centre and is given as follows:

(1) let r number of the real poles in a cluster be $|p_1| < |p_2| \cdots < |p_r|$,

(2) set $j = 1$,

(3) find pole cluster centre by $c_j = \left[\sum_{i=1}^{r} (-1/|p_i|) \div r \right]^{-1}$,

(4) set $j = j + 1$,

(5) now find a modified cluster centre from $c_j = \left[(-1/|p_1| + -1/|c_{j-1}|) \div 2 \right]^{-1}$,

(6) is $j = r$?, if No, then go to step (4) otherwise go to step (7),

(7) take a modified cluster centre of the kth-cluster as $p_{ek} = c_j$.

For synthesizing the common denominator polynomial, one of the following cases may occur.

Case 1. If all the modified cluster centres are real, then denominator polynomial of the kth-order reduced model can be obtained as

$$D_k(s) = (s - p_{e1})(s - p_{e2}) \cdots (s - p_{ek}), \quad (7)$$

where $p_{e1}, p_{e2}, \ldots, p_{ek}$ are the first-, second-, $\ldots$, kth-modified cluster centre, respectively.

Case 2. If all the modified cluster centres are complex conjugate, then the kth-order denominator polynomial is taken as

$$D_k(s) = (s - \overset{*}{\Phi}_{e1})(s - \overset{\circ}{\Phi}_{e1}) \cdots (s - \overset{*}{\Phi}_{ek/2})(s - \overset{\circ}{\Phi}_{ek/2}). \tag{8}$$

Case 3. If some cluster centres are real and some are complex conjugate, then this case holds.

Let $(k - 2)$ cluster centres are real and one pair of cluster centre is complex conjugate, then the kth-order denominator can be obtained as

$$D_k(s) = (s - p_{e1})(s - p_{e2}) \cdots (s - p_{e(k-2)})(s - \overset{*}{\Phi}_{e1})(s - \overset{\circ}{\Phi}_{e1}). \tag{9}$$

Step 2. Determination of the numerator $c_{ij}(s)$ of the reduced transfer matrix $r_{ij}(s)$ using GA.

In this paper, GA has been applied to minimize the objective function "F_{ij}," which is an integral square error ISE [9] between the unit step responses of the elements of the original and the reduced system and is given by

$$F_{ij} = \int_0^\infty [g_{ij}(t) - r_{ij}(t)]^2 dt, \quad i = 1, 2, \ldots, q; \ j = 1, 2, \ldots, p, \tag{10}$$

where $g_{ij}(t)$ and $r_{ij}(t)$ are the unit step responses of the elements of original high-order system $[G(s)]$ and the reduced-order model $[R_k(s)]$, respectively. The coefficients $c_j; 1 \leq j \leq k - 1$ of the numerator element $c_{ij}(s)$ are determined with suitable GA parameters.

To ensure the zero steady-state error, the coefficient c_0 is obtained as

$$c_0 = \frac{a_0}{b_0} \cdot d_0. \tag{11}$$

The computational flowchart of the GA optimization is shown in Figure 1.

3. Numerical Example

To demonstrate the accuracy and usefulness of the proposed method, one numerical example is taken from the literature and the second-order reduced model is obtained using the suggested algorithm.

Consider a sixth-order system [2] having two-input and two-output described by the transfer matrix:

$$[G(s)] = \begin{bmatrix} \dfrac{2(s+5)}{(s+1)(s+10)} & \dfrac{(s+4)}{(s+2)(s+5)} \\ \dfrac{(s+10)}{(s+1)(s+20)} & \dfrac{(s+6)}{(s+2)(s+3)} \end{bmatrix}, \tag{12}$$

$$= \frac{1}{D_6(s)} \begin{bmatrix} a_{11}(s) & a_{12}(s) \\ a_{21}(s) & a_{22}(s) \end{bmatrix},$$

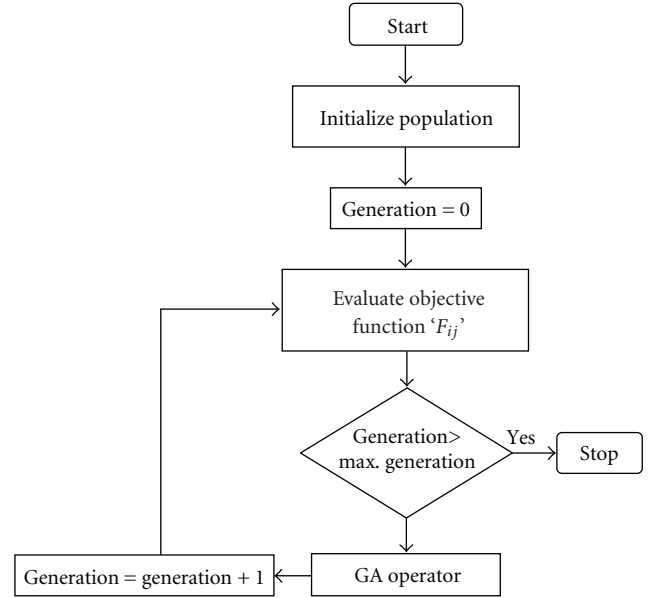where $D(s)$ is the common denominator polynomial.

FIGURE 1: Flowchart of genetic algorithm.

The poles are $-1, -2, -3, -5, -10, -20$. Let the first and second clusters contain the poles $-1, -2$ and $-3, -5, -10, -20$, respectively for getting second-order reduced model.

Now using Step 1, the modified cluster centres are obtained as

$$p_{e1} = -1.1428, \qquad p_{e2} = -3.1946. \tag{13}$$

Using Case 1, the denominator polynomial for the second-order reduced model is obtained as

$$D_2(s) = (s + 1.1428)(s + 3.1946) = 3.65079 + 4.3374s + s^2. \tag{14}$$

Step 2 of the proposed algorithm is successively applied to each element of the high-order original MIMO system and the reduced models $r_{ij}(s)$ of the $[R_2(s)]$ and then $c_{ij}(s): 1 \leq i \leq 2; \ 1 \leq j \leq 2$ are obtained as

$$\begin{aligned} c_{11}(s) &= 3.65079 + 1.18156s, \\ c_{12}(s) &= 1.46031 + 1.04664s, \\ c_{21}(s) &= 1.82539 + 0.49819s, \\ c_{22}(s) &= 3.65079 + 1.6911s. \end{aligned} \tag{15}$$

Therefore, finally the second-order reduced model is obtained as

$$[R_2(s)] = \frac{1}{3.65079 + 4.3374s + s^2}$$

$$\times \begin{bmatrix} 3.65079 + 1.18156s & 1.46031 + 1.04664s \\ 1.82539 + 0.49819s & 3.65079 + 1.6911s \end{bmatrix}. \tag{16}$$

The step responses of the reduced-order models $r_{ij}(s)$ are compared with the original system $g_{ij}(s)$ and are shown in Figure 2 and the proposed method is compared with the other well-known order-reduction techniques available in literature and are shown in the Table 1 by comparing

TABLE 1: Comparison of reduction methods.

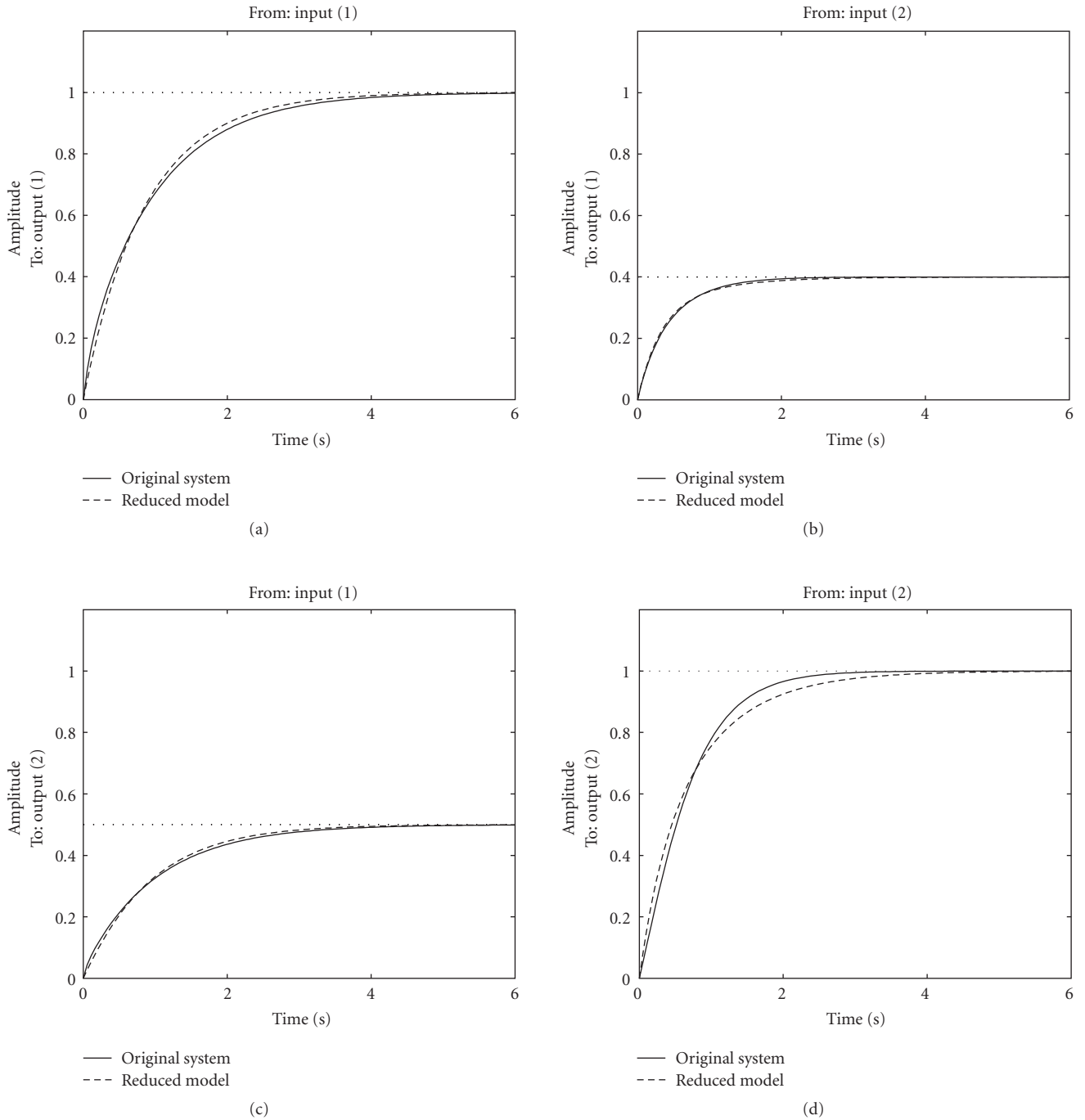|	ISE for r_{ij} ($i = 1, 2; j = 1, 2$)			
Reduction method	r_{11}	r_{12}	r_{21}	r_{22}
Proposed method	0.001515	7.845×10^{-5}	0.000299	0.004681
Parmar et al. [9]	0.014498	0.008744	0.002538	0.015741
Prasad and Pal [14]	0.136484	0.002446	0.040291	0.067902
Safonov and Chiang [15]	0.590617	0.037129	0.007328	1.066123
Prasad et al. [1]	0.030689	0.000256	0.261963	0.021683

FIGURE 2: Comparison of the step responses.

the integral square error ISE in between the step responses of the original $g_{ij}(s)$ and reduced $r_{ij}(s)$-order systems. The ISE is given as

$$\text{ISE} = \int_0^\infty \left[g_{ij}(t) - r_{ij}(t) \right]^2 dt, \qquad (17)$$

where, $i = 1, 2$, $j = 1, 2$ and $g_{ij}(t), r_{ij}(t)$ are the unit step responses of the original and reduced systems respectively for ith-output with jth-input.

4. Conclusions

A new mixed method which combines the advantages of the modified pole clustering and the integral square error minimization by using GA has been presented to derive stable reduced-order models of the linear time-invariant MIMO systems.

In this method, the common denominator polynomial of the reduced transfer function matrix is synthesized using the modified pole clustering, and the coefficients of the numerator of the reduced model are computed by minimizing the integral square error between the step responses of the original and reduced system using GA. The method is simple, rugged, and computer-oriented. The proposed algorithm has been applied on the system having two inputs and two outputs to get second-order reduced model. The comparison of the step responses of the original and reduced system is shown in Figure 2 and ISE is calculated between the original and reduced system and compared in the tabular form as given in Table 1, from which it is clear that the proposed method is comparable in quality with the other well-known order-reduction techniques for MIMO systems. The method also preserves the model stability and avoids any steady-state error between the time responses of the original and reduced systems. The proposed method may be extended to unstable systems and is reported elsewhere.

References

[1] R. Prasad, J. Pal, and A. K. Pant, "Multivariable system approximation using polynomial derivatives," *Journal of the Institution of Engineers*, vol. 76, pp. 186–188, 1995.

[2] Y. Bistritz and U. Shaked, "Minimal Pade model reduction for multivariable systems," *Journal of Dynamic Systems, Measurement and Control*, vol. 106, no. 4, pp. 293–299, 1984.

[3] C. F. Chen, "Model reduction of multivariable control systems by means of matrix continued fractions," *International Journal of Control*, vol. 20, no. 2, pp. 225–238, 1974.

[4] M. R. Calfe and M. Healey, "Continued fraction model reduction technique for multivariable systems," *Proceedings of the Institution of Electrical Engineers*, vol. 121, no. 5, pp. 393–395, 1974.

[5] R. Prasad, "Pade type model order reduction for multivariable systems using routh approximation," *Computers & Electrical Engineering*, vol. 26, no. 6, pp. 445–459, 2000.

[6] R. Prasad, A. K. Mittal, and S. P. Sharma, "A mixed method for the reduction of multi-variable systems," *Journal of the Institution of Engineers*, vol. 85, pp. 177–181, 2005.

[7] L. Shieh and Y. Wei, "A mixed method for multivariable system reduction," *IEEE Transactions on Automatic Control*, vol. 20, no. 3, pp. 429–432, 1975.

[8] S. Mukherjee and R. N. Mishra, "Reduced order modelling of linear multivariable systems using an error minimization technique," *Journal of the Franklin Institute*, vol. 325, no. 2, pp. 235–245, 1988.

[9] G. Parmar, R. Prasad, and S. Mukherjee, "Order reduction of linear dynamic systems using stability equation method and GA," *International Journal of Computer, Information, and Systems Science, and Engineering*, vol. 1, no. 1, pp. 26–32, 2007.

[10] S. S. Lamba, R. Gorez, and B. Bandyopadhyay, "New reduction technique by step error minimization for multivariable systems," *International Journal of Systems Science*, vol. 19, no. 6, pp. 999–1009, 1988.

[11] Y. Zheng and S. Kiyooka, "Genetic Algorithms Applications: Assignment #2 for Dr. Z. Dong," November 1999, http://www.me.uvic.ca/~zdong/courses/mech620/GA_App.PDF.

[12] J. Pal, A. K. Sinha, and N. K. Sinha, "Reduced order modelling using pole-clustering and time-moment matching," *Journal of the Institution of Engineers*, vol. 76, pp. 1–6, 1995.

[13] A. K. Sinha and J. Pal, "Simulation based reduced order modelling using a clustering technique," *Computers & Electrical Engineering*, vol. 16, no. 3, pp. 159–169, 1990.

[14] R. Prasad and J. Pal, "Use of continued fraction expansion for stable reduction of linear multivariable systems," *Journal of the Institution of Engineers*, vol. 72, pp. 43–47, 1991.

[15] M. G. Safonov and R. Y. Chiang, "Model reduction for robust control: a schur relative error method," *International Journal of Adaptive Control and Signal Processing*, vol. 2, no. 4, pp. 259–272, 1988.

Special Issue on
Robotic Astronomy

Call for Papers

The number of automatic astronomical facilities worldwide continues to grow, and the level of robotisation, autonomy, and networking is increasing as well. This has a strong impact in many astrophysical fields, like the search for extrasolar planets, the monitoring of variable stars in our galaxy, the study of active galactic nuclei, the detection and monitoring of supernovae, and the immediate follow-up of high-energy transients such as gamma-ray bursts.

The main focus of this special issue will be on the new and existing astronomical facilities whose goal is to observe a wide variety of astrophysical targets with no (or very little) human interaction. The special issue will become an international forum for researchers to summarize the most recent developments and ideas in the field, with a special emphasis given to the technical and observational results obtained within the last five years. The topics to be covered include, but not limited to:

- Robotic astronomy: historical perspective
- Existing robotic observatories worldwide
- New hardware and software developments
- Real-time analysis pipelines
- Archiving the data
- Telescope and observatory control systems
- Transient detection and classification
- Protocols for robotic telescope networks
- Standards and protocols for transient reporting
- Scientific results obtained by means of robotic observatories
- Global networks
- Future strategies

Before submission authors should carefully read over the journal's Author Guidelines, which are located at http://www.hindawi.com/journals/aa/guidelines.html. Authors should follow the Advances in Astronomy manuscript format described at the journal site http://www.hindawi.com/journals/aa/. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at http://mts.hindawi.com/ according to the following timetable:

Manuscript Due	June 15, 2009
First Round of Reviews	September 15, 2009
Publication Date	December 15, 2009

Lead Guest Editor

Alberto J. Castro-Tirado, Instituto de Astrofísica de Andalucía, P.O. Box 03004, 18080 Granada, Spain; ajct@iaa.es

Guest Editors

Joshua S. Bloom, Astronomy Department, University of California, Berkeley, CA 94720, USA; jbloom@astro.berkeley.edu

Lorraine Hanlon, School of Physics, University College Dublin, Belfield, Dublin 4, Ireland; lorraine.hanlon@ucd.ie

Frederic Hessman, Institut für Astrophysik, Georg-August-Universität, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany; hessman@astro.physik.uni-goettingen.de

Taro Kotani, Department of Physics and Mathematics, Aoyama Gakuin University, 5-10-1 Fuchinobe, Sagamihara, Kanagawa 229-8558, Japan; kotani@hp.phys.titech.ac.jp

Special Issue on
Fuzzy Logic Techniques for Clean Environment

Call for Papers

The fuzzy technique for clean energy, solar and wind energy, is the most readily available source of energy, and one of the important sources of the renewable energy, because it is nonpolluting and, therefore, helps in lessening the greenhouse effect. The benefits arising from the utilization of solar and wind energy systems can be categorized into two sections: energy saving and the decrease of environmental pollution. The clean energy saving benefits come from the reduction in electricity consumption and from using any conventional energy supplier, which can avoid the expenditure of fuel supply. The other main benefit of the renewable energy is the decrease of environmental pollution, which can be achieved by the reduction of emissions due to the usage of electricity and conventional power stations. Electricity production using solar and wind energy is of the main research areas at present in the field of renewable energies, the significant price fluctuations are seen for the fossil fuel in one hand, and the trend toward privatization that dominates the power markets these days in the other hand, will drive the demand for solar technologies in the near term. The process of solar distillation is used worldwide for arid communities that do not have access to potable water. Also some solar technologies provide other benefits beside power generation, that is, fresh water (using desalination techniques).

The main focus of this special issue will be on the applications of fuzzy techniques for clean energy. We are particularly interested in manuscripts that report the fuzzy techniques applications of clean energy (solar, wind, desalination, etc.). Potential topics include, but are not limited to:

- Solar power station
- Wind power
- Photovoltaic and renewable energy engineering
- Renewable energy commercialization
- Solar cities
- Solar powered desalination unit
- Solar power
- Solar power plants
- Solar systems (company)
- World solar challenge

- Seawater desalination to produce fresh water
- Desalination for long-term water security

Before submission authors should carefully read over the journal's Author Guidelines, which are located at http://www.hindawi.com/journals/afs/guidelines.html. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at http://mts.hindawi.com/, according to the following timetable:

Manuscript Due	October 1, 2009
First Round of Reviews	January 1, 2010
Publication Date	April 1, 2010

Guest Editors

Rustom M. Mamlook, Middle East University for Graduate Studies, Amman, Jordan; rstmamlk@hotmail.com

Guest Editors

S. Paramasivam, ESAB Engineering Services Limited, Tamil Nadu 600 058, India; param@ieee.org

Mohammad Ameen Al-Jarrah, American University of Sharjah, P.O. Box 26666, Sharjah, UAE; mjarrah@aus.edu

Zeki Ayag, Kadir Has University, 34083 Istanbul, Turkey; zekia@khas.edu.tr

Ashok B. Kulkarni, University of Technology, Kingston 6, Jamaica; kulkarniab2@rediffmail.com

Special Issue on

Selected Papers from Workshop on Synergies in Communications and Localization (SyCoLo 2009)

Call for Papers

In conjunction with the IEEE International Conference on Communications (ICC) 2009 in Dresden, Germany, the International Workshop on Synergies in Communications and Localization (SyCoLo 2009) will be held.

The main objective of this workshop is to show how wireless communications and navigation/localization techniques can benefit from each other. With respect to these synergies the workshop aims at the following fundamental questions:

- How can navigation systems benefit from existing communications systems?
- How can communication systems benefit from positioning information of mobile terminals?

This workshop, whose proposal was jointly generated by the EU Research Projects WHERE and NEWCOM++, aims at inspiring the development of new position-aware procedures to enhance the efficiency of communication networks, and of new positioning algorithms based both on (outdoor or indoor) wireless communications and on satellite navigation systems.

The SyCoLo 2009 is, therefore, well in agreement with the new IJNO journal aims at promoting and diffusing the aims of joint communications and navigation among universities, research institutions, and industries.

This proposed IJNO Special Issue focuses all the research themes related to the timing aspects of joint communications and navigation, and starts from the SyCoLo 2009 where the Guest Editors will attend the different sessions and directly invite the authors of the most promising papers to submit an extended version of their papers to the journal.

The proposed Guest Editors are also part of the Scientific Committees of the SyCoLo 2009, therefore, directly involved in the evaluation of submitted papers.

Topics of interest will include, but are not limited to:

- Hybrid positioning using both wireless communications and satellite navigation systems
- Resource management with positioning information
- Location-aware PHY/MAC algorithms/procedures
- Indoor positioning combined with short-range communications
- Signal processing techniques for (seamless) indoor/outdoor localization

Before submission authors should carefully read over the journal's Author Guidelines, which are located at http://www.hindawi.com/journals/ijno/guidelines.html. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at http://mts.hindawi.com/ according to the following timetable:

Manuscript Due	October 1, 2009
First Round of Reviews	January 1, 2010
Publication Date	April 1, 2010

Lead Guest Editor

Ronald Raulefs, German Aerospace Center (DLR), Institute of Communications and Navigation, Oberpfaffenhofen, Wessling 82234, Germany; ronald.raulefs@dlr.de

Guest Editors

Simon Plass, Institute of Communications and Navigation, German Aerospace Center (DLR), 82234 Wessling, Germany; simon.plass@dlr.de

Marco Luise, Dipartimento di Ingegneria dell'Informazione, Università di Pisa, Via G. Caruso 16, 56126 Pisa, Italy; marco.luise@iet.unipi.it