The Roesser model and its various applications

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Abstract—**As human needs are increasing day by day to satisfying that technologies should also be develop. Multidimensional technology has the variety of signals which are available, to satisfy various criteria in multidimensional systems. There are few state space model structures i.e. Roesser, FM (fornasinimarchesini) first model, FM second model, Attasi model, GR model, these are discrete state space models we have been using since last few decades. These models can be used for various purposes because when we embed any system in these models, then system is represented in efficient manner there are various application for these models**

So in this paper purpose is to highlight more recent areas where Roesser model has been used as applications. As well as some applications in terms of stability is discussed with example.

Index Terms—*Roesser model; Applications of Roesser model; State space modeling*

I. Introduction

Multidimensional systems has been continuously growing research interest area due to their applications in various important area such as image processing, Signal processing, seismographic data processing, water steam heating, DSP filters etc. [2]

All the above areas are n-D systems in nature, they have more than one variable, so there can be problem like stability can be difficult to solve in n-D systems compare to 1-D system. The reason is that the fundamental theorem of algebra cannot be extended to multivariate polynomials. Several ways are commonly used to represent the operation involved in any digital processing. These methods can include transfer functions, convolution summations, and partial difference (recursive) equations. We can use above methods to solve 2-D problems i.e if we take image as example, The partial deference equation can be use to remove corrupted noise in image which is described by habibi, the model corresponds to 2-D extension of kalman filters. More ever image is best and common example of multi dimensions systems, where image properties varying along the horizontal and vertical directions, hence we can call it 2-D systems. As we can represent 1-d system, 2-D system can be represented by either transfer function models using -2D z transform models or by using state space models. [1]

For modeling physical systems the desired accuracy lead to a high dynamic order, The model like Roesser (R)[1] model Fornasini-Marchesini (FM),[3,4]Givone–Roesser (GR) are best state space models which gives best results in analysis of n-D systems, Because state space model is a general powerfultool that is used to unify the research and study of n-D linear systems.FM and R are equivalent in homogeneous case. Fornasini-marchesini and Robert p .Roesser have published many literatures papers in between 1970 to 1980 related to modeling of physical system. This was trending times in researching in n-D systems modeling.

In that golden decade, roesser has published new state space model in 1975 in that, he has taken image as example where a discrete model with a single coordinate in time is replaced by a model with two co-ordinates in space which are vertical and horizontal. He took circuit approach for developing state space model. Rosser model can continuous on both dimensions or mixed i.e one dimensions is continuous and other one can be discrete. R model is most general state space model among all state space models because other models like attasi ,FM model can be easily imbedded in R model that can help to use to analysis more towards nD systems.

In initial time Rosser model was used in Image processing area, but then after it has been used in many applications, such as in 2-D control systems, in discrezation of partial differential equations, design of 2-D digital filters structures, in linear repetitive processes, in realization and model reduction of 2-D system and 2-D texture synthesis and classifications, iterative learning control and many more. In this paper latest applications based on Roesser model is discussed and its basic implementation summery discussed.

Rosser model can be described as below

$$x(i,j) = \begin{pmatrix} x^h(i,j) \\ x^v(i,j) \end{pmatrix},$$

Where x is local state, x^h an n-vector is horizontal state, x^v an m-vector is vertical state.

$$\begin{pmatrix} x^h(i+1,j) \\ x^v(i,j+1) \end{pmatrix} = \begin{pmatrix} A_1 & A_2 \\ A_3 & A_4 \end{pmatrix} \begin{pmatrix} x^h(i,j) \\ x^v(i,j) \end{pmatrix} + \begin{pmatrix} B_1 \\ B_2 \end{pmatrix} u(i,j),$$

$$y(i,j) = (C_1 C_2) \begin{pmatrix} x^h(i,j) \\ x^v(i,j) \end{pmatrix} + Du(i,j),$$

$u(i,j) \epsilon R^m$ is the input vector,

$y(i,j) \epsilon R^p$ is the output vector and A1, A2, A3, A4, B1, B2, C, D are real matrices [1].

II. Stability

As stability is a very important criterion for any physical system to working it properly. Test for stability is of 2-D system is exit in frequency domain. As number of dimensions are increases in systems stability of systems decreases. Roesser model is one of the best model by which we can conclude some stability criteria using different methods withRoesser model.

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Some different methods with Roesser model to establish stability are discussed below.

Lyapunov equations can be use for Roesser model to check stability.it is be used as sufficient condition for 2D systems with structured and un structured delayed perturbations [5]. For stability we can also use exponential stability definitions with existing stability criteria in linear case. In that exponential stability is equivalent to the asymptotic stability and the characteristic polynomial-based stability is equal to sufficient and necessary conditions for the exponential stability. Where property of exponential stability is characterized by use of vector lyapunov function[6]-[7].Roesser model also uses in non-linear system for deriving its stability, for non-linear system R model can be used as fuzzy model form which helps to do stability analysis of non-linear systems [8]. R model can be used for establish stability with delay for 2-D system, to establish sufficient condition for 2-D system to be asymptotically stable in the presence of delay, A delay- depend liner matrix inequality approach can be use [9] for asymptotic stability Lyapunov equations $A^TP+AP=Q$ with positive definite block matrix $P=P^T$ together with simple additional condition is sufficient, it can use for wide range dynamic application [10]. Lyapunov methods are generally used for R model to derive different criteria; it is also used as stability derivations in most of the papers. Below some of latest examples of application where Roesser model used for stability.The 2-D Roesser model is used in automated irrigation channels and tools for practical stability [11]. Using R model sufficient condition for existence of desired a state feedback controller are obtained [12] .We can also derive stability of shift-varying system [13]. The decomposition of discrete 3D system in to classical 1D state space for stability [14].

III. Grid sensor networks

Sensor networks are very useful now a day, As we are going toward new technology like 5G. Sensor nodes are distributed in space. They collect information from surroundings and send to the observers. Sensor networks have been used in wide variety of areas, such as health monitoring, Fire detection in jungle, Temperature measurement for different places, water purity level measurement etc.

Roesser model was developed for 2-D systems as we know, but for grid sensor networks we take as 3-D system. There can be different assumption for 3-D system, i.e [15] they took 3-D as vertical, horizontal, and temporal dimensions respectively, moreover as sensors should be more efficient and energy saver, the communications between two or more sensors should be reliable, for that [16] assumed sensor grid networks in 3-D, in that 3d network they assumed a 2D rectangular grid sensor network of finite size. More they assumed that sample of sensor input over multiple sampling instance are incorporated in to processing algorithm, the third dimension in that system is time.

According to [15], Roesser model can be used to sensor by using below 3-D equations.

$$\begin{pmatrix} x^h(n1+1,n2,t) \\ x^y(n1,n2+1,t) \\ x^t(n1,n2,t+1) \end{pmatrix} = A \begin{pmatrix} x^h(n1,n2,t) \\ x^y(n1,n2,t) \\ x^t(n1,n2,t) \end{pmatrix} + BU(n1,n2,t),$$

$$Y(n1,n2,t) = C \begin{pmatrix} x^h(n1,n2,t) \\ x^y(n1,n2,t) \\ x^t(n1,n2,t) \end{pmatrix} + DU(n1,n2,t).$$

Where $Y(n_1,n_2,t)$ is output, $U(n_1,n_2,t)$ is input ,$x^h(n_1,n_2,t)$ÃR^{r1}; $x^y(n_1,n_2,t)$ÃR^{r2}; $x^t(n_1,n_2,t)$ÃR^{r3} are horizontal, vertical and temporal state vectors respectively. A,B,C,D are real matrices.

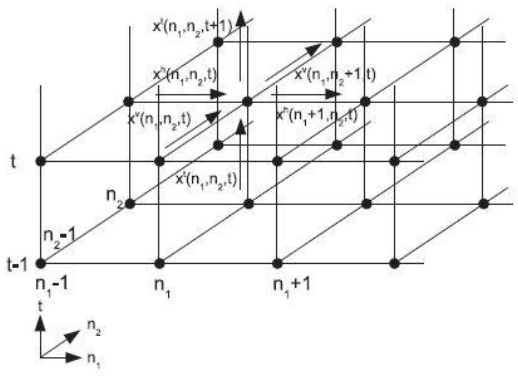

Fig. 1. Communication of state vectors between nodes in the network

Above figure 1 is example of implementation of sensors in networks.

Roesser model helps to implement grid sensor network in distributed fashion [17], using this model in sensor network we can make it easily scalable and reconfigurable.

IV. Filters

R model can be use for 2D FIR, IIR, Digital filters, H∞ filters etc.

A. FIR Filter

A Orthogonal Roesser model synthesis for 2D FIR system is Presented [18] those types of approaches allow to utilize a full rank factorization applied to a co-efficient matrix of 2-D transfer function, which made with a cascade connection of two 1-D system, that why required to synthesize an orthogonal 1-D state space realization for each 1-D T.F(transfer function) separately and last we recombine both realizations in to an orthogonal Roesser model.

B. IIR Filter

R model can be used to IIR filter that can help to develop 2-D state digital filter. Which can use in high order error feedback that offers much improved performance [19].

C. Digital Filter

R model with wiener process noise helps to eliminate overflow oscillation of 2D digital filter. Which helps to remove attenuation of the effect of wiener process noise to prescribed level and also improve stability in digital filter [20].

D. H∞ Filter

State estimation is very important problem in the field of signal processing and control, kamal filtering approach, which provides an optimal estimation of state variable in the sense that the co-variance of the estimation error is minimized for this information should be very accurate but some time it is not satisfying in practical applications for that H∞ filters has been used [21]. one of the most popular strategies for error estimation is H∞ filtering, which is famous in recent days, Which helps to remove unwanted noise [22].

V. FAULT DETECTIONS

The Fault detection has been interesting subject of researchers due to increasing demand for reliability safety, survivability, maintainability, in applications likes aerospace systems and industrial processes and lot of detection. There are several methods available in literatures for fault detection, among all model based is used frequently. Many disturbance and fault signals in reality are in finite frequency domains, for that standard methods should be design, As compare to 1D system 2D system should also easily fault detectable for that there are some methods which are available in frequency domain [23]. They proposed different method for fault detection in that they used Roesser model for better performance. In that method they take support of frequency methods, as Kalman-yakubovich-popov lemma are developed for different cases for 2 D system. Based on that finite frequency fault detection observed for 2D continuous discrete system in Roesser model, they designed LMI- based finite frequency fault detection for 2D continuous discrete in R model.

VI. ILC AS 2-D SYSTEM

Most of the industrial applications are involved in same executing operation for many times over a fixed interval, when each operation is complete. It will reset the staring location takes places and go for next operation. These types of applications are widely using in robotics, hard disk drives, chemical batch process, and urban traffic systems. We can say that ILC (iterative learning control) is a typical data driven technique.

n-DRoesser system can be useful to describe the entire dynamics involved in ILC systems with relative degree, ILC can be presented directly be applying the theory of continuous-discrete or discrete 2-D roesser model for which necessary and sufficient condition can be provided in form of first nonzero Markov parameter matrix [24].

According to [25] ILC can be treated as 2D system where one direction of information is from trial to trial and other is along a trial, Since trial duration is finite ,ILC can therefore be treated as a repetitive process. These process form a distinct class of 2-D system where information propagation in one of two independent directions only occurs over a finite duration. According to [26] 2-D model based ILC design, where controller design is transformed in to stabilization of a 2D-stochastic-system described by R model. 2D Roesser System is established to describe the entire dynamics of ILC.

VII. CHECKING STABILITY CRITERIA USING OUR DERIVED THEOREMS

Table II Stability theorems 1

Models/TH	TH1
FM2	$\begin{pmatrix} -P & PA & 0 & PH \\ A^TP & -Q & \varepsilon E^T & 0 \\ 0 & \varepsilon E & -\varepsilon I & 0 \\ H^TP & 0 & 0 & -\varepsilon I \end{pmatrix} > 0$
R	$\begin{pmatrix} -P & PA & 0 & PH \\ A^TP & -P & kE^T & 0 \\ 0 & kE & -kI & 0 \\ H^TP & 0 & 0 & -kI \end{pmatrix} > 0$

Table III Stability theorems 2

Models/T-H	TH2
FM2	$\begin{pmatrix} P_1-\varepsilon_1E_1^TE_1 & 0 & A_1^TP & PH_1 & PH_2 \\ 0 & P_1-\varepsilon_1E_1^TE_1 & A_2^TP & 0 & 0 \\ PA_1 & PA_1 & P & 0 & 0 \\ H_1^TP & 0 & 0 & \varepsilon_1I & 0 \\ H_2^TP & 0 & 0 & 0 & \varepsilon_2I \end{pmatrix}>0$
R	$\begin{pmatrix} P_1-\varepsilon_1E_1^TE_1-\varepsilon_3E_3^TE_3 & 0 & A_1^TP_1 & A_3^TP_2 & 0 & 0 & 0 & 0 \\ 0 & P_2-\varepsilon_2E_2^TE_2-\varepsilon_4E_4^TE_4 & A_1^TP_1 & A_4^TP_2 & 0 & 0 & 0 & 0 \\ P_1A_1 & P_1A_2 & P & 0 & P_1H_1 & P_1H_2 & 0 & 0 \\ P_2A_3 & P_2A_4 & 0 & P_2 & 0 & 0 & P_2H_3 & P_2H_4 \\ 0 & 0 & H_1^TP_1 & 0 & \varepsilon_1I & 0 & 0 & 0 \\ 0 & 0 & H_2^TP_1 & 0 & 0 & \varepsilon_2I & 0 & 0 \\ 0 & 0 & 0 & H_3^TP_2 & 0 & 0 & \varepsilon_3I & 0 \\ 0 & 0 & 0 & H_4^TP_2 & 0 & 0 & 0 & \varepsilon_4I \end{pmatrix} > 0$

Above Table II and III are stability theorems which we have derived for FM2 and R [30] model, for FM1 details has been taken from [28]. We have derived two theorems for each models and made flow chart [28] if sufficient condition satisfied for first theorem its stable else check with 2[nd]criteria. For applications purpose we haveBorrowed example of [29] LSIV 2-D Attasi's model filter (PSV system) using circulant matrices to test our derived stability criteria.

$$\overline{A_1} = \begin{pmatrix} 0.5 & -0.5 & 0.125 & -0.125 \\ -0.125 & 0.5 & -0.5 & 0.125 \\ 0.125 & -0.125 & 0.5 & -0.5 \\ -0.5 & 0.125 & -0.125 & 0.5 \end{pmatrix},$$

$$\overline{A_2} = \begin{pmatrix} 0.5 & 0 & -0.015 & 0.25 \\ 0.25 & 0.5 & 0 & -0.015 \\ -0.015 & 0.25 & 0.5 & 0 \\ 0 & -0.015 & 0.25 & 0.5 \end{pmatrix},$$

$$\bar{B} = (1 \quad 0.39 \quad -1 \quad 0.45)^T,$$

$$\bar{C} = (1 \quad -1 \quad -1 \quad 1),$$

$$A_1 = \overline{A_1} \ and \ C = \bar{C},$$

$$A_2(0,0) = \begin{pmatrix} 0.5 & 0.5 & 0 & -0.5 \\ -0.5 & 0.5 & 0.5 & 0.5 \\ 0 & -0.5 & 0.5 & 0.5 \\ 0.5 & 0 & -0.5 & 0.5 \end{pmatrix},$$

$$A_2(0,1) = \begin{pmatrix} 0.5 & 0 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0 & 0.5 \\ 0.5 & 0.5 & 0.5 & 0 \\ 0 & 0.5 & 0.5 & 0.5 \end{pmatrix},$$

$$B(0,0) = (-1 \quad -1 \quad -0.25 \quad -1)^T$$

$$B(0,1) = (1 \quad -0.25 \quad -1 \quad -0.5)^T$$

$$A_0 = A_1A_2.$$

Period of PSV in this case is 1:2.

for FM2:

$$A = (A_1 \quad A_2),$$

where $A_1 = \overline{A_1}$,

$$A_2(0,0) = \begin{pmatrix} 0.5 & 0.5 & 0 & -0.5 \\ -0.5 & 0.5 & 0.5 & 0.5 \\ 0 & -0.5 & 0.5 & 0.5 \\ 0.5 & 0 & -0.5 & 0.5 \end{pmatrix},$$

$$A_2(0,1) = \begin{pmatrix} 0.5 & 0 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0 & 0.5 \\ 0.5 & 0.5 & 0.5 & 0 \\ 0 & 0.5 & 0.5 & 0.5 \end{pmatrix},$$

$$\Delta A = A(A_1, A_2(0,0))\text{-}A(A_1, A_2(0,1));$$

$$\Delta A = HFE.$$

$$\Delta A = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0.5 & 0.5 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0.5 & 0 \\ 0 & 0 & 0 & 0 & 0.5 & 1 & 0 & 0.5 \\ 0 & 0 & 0 & 0 & 0.5 & 0.5 & 1 & 0 \end{pmatrix},$$

Aftergetting, H F, E we can follows steps [28] for stability analysis.

For FM1:

$$\mathrm{A} = (A_0 \quad A_1 \quad A_2),$$

ForR:

$$A = \begin{pmatrix} A_{00} & A_{01} \\ A_{10} & A_{11} \end{pmatrix},$$

Values are available for FM1 and for FM2 as shown previously, to convert FM1 matrices values in R Form we have taken reference of [14] and converted in suitable matrices form. FM1 and R are not independent and can be mutually recasted.

FM1 in equation form:

$$E' x(i+1, j+1) = A_1 x(i+1, j+1) + A_2 x(i+1, j) + A_0(i,j) + Bu(i,j) + B_1 u(i, j+1) + B_2 u(i+1, j),$$

R in equation form:

$$E \begin{pmatrix} x^h(i+1, j) \\ x^v(i, j+1) \end{pmatrix} = A \begin{pmatrix} x^h(i,j) \\ x^v(i,j) \end{pmatrix} + Bu(i,j)\ ,$$

$$\text{Where} \mathrm{E} = I_N,\ N = t_1 + t_2.$$

To convert FM1 in to R model we are assuming horizontal vector $\xi(i,j) = E' x(i, j+1) - A_1 x(i,j)$, and equation of FM1 in R form would be

$$\begin{pmatrix} I_n & -A_2 \\ 0 & E' \end{pmatrix} \begin{pmatrix} \xi(i+1, j) \\ x(i, j+1) \end{pmatrix} = \begin{pmatrix} 0 & A_3 \\ I_n & A_1 \end{pmatrix} \begin{pmatrix} \xi(i,j) \\ x(i,j) \end{pmatrix} + \begin{pmatrix} B \\ 0 \end{pmatrix} u(i,j).$$

Taking this concept we get matrix ‘A’ for R which is,

$$A = \begin{pmatrix} 0 & 0 & 0 & 0 & 0.5000 & 0 & -0.0150 & 0.2500 \\ 0 & 0 & 0 & 0 & 0.2500 & 0.5000 & 0 & -0.0150 \\ 0 & 0 & 0 & 0 & -0.0150 & 0.2500 & 0.5000 & 0 \\ 0 & 0 & 0 & 0 & 0 & -0.0150 & 0.2500 & 0.5000 \\ 1.0000 & 0 & 0 & 0 & 0.7500 & -0.5000 & 0.1231 & -0.1563 \\ 0 & 1.0000 & 0 & 0 & -0.1563 & 0.7500 & -0.5000 & 0.1231 \\ 0 & 0 & 1.0000 & 0 & 0.1231 & -0.1563 & 0.7500 & -0.5000 \\ 0 & 0 & 0 & 1.0000 & -0.5000 & 0.1231 & -0.1563 & 0.7500 \end{pmatrix}$$

Using these matrices for FM1, FM2 and R stability analysis has been done using previous steps [28] for PSV system.

Table III Stability Analysis For Above Example

	FM1		FM2		R	
	TH1	TH2	TH1	TH2	TH1	TH2
Stability condition	×	√	√	-	√	-

Such types of analysis have been done for check stability criteria using our derived criteria to check our stability analysis.

VIII. Conclusion

As nD system has been used in various applications, Dynamics of arise in control and stability. One where application has lagged far behind the theoretical development. This paper has considered some latest recent developing area where Roesser model has been used for various desired development also we have done stability analysis of Roesser model as well as others model using our derived criteria

REFERENCES

[1] R. P. Roesser, “A discrete state-space model for linear image processing,” *IEEE Trans. Automat. Control*, vol. 20, pp. 1-10, 1975

[2] Manish Tiwari and AmitDhawa, “ A Survey on Stability of 2-D Discrete Systems Described by Fornasini-Marchesini First Model,” 978-1-4244-8542-0/10/$26.00 ©2010 IEEE

[3] E. Fornasini, G. Marchesini, “State-space realization theory of two dimensional filters,” *IEEE Trans. Automat. Control*, vol. 21, pp. 484-492, 1976

[4] E. Fornasini, G. Marchesini, “Doubly indexed dynamical systems: Statespace models and structural properties,” *Math. Syst. Theory*, vol. 12, pp.59-72, 1978..

[5] S.X Ye, J.Z Li, "Robust control for a class of 2-D discrete uncertain delayed systems", Tenth IEEE Int. Conf. on Control and Automation (ICCA), pp. 1048-1052, 2013

[6] NimaYeganefarm,NaderYeganefar, Olivier Bachelier ,Emmanuel Moulay” Exponential stability for 2D systems: the linear case” 8th Int. Workshop on Multidimensional Systems (nDS’13), Erlangen, Germany, Sep 9–11 2013

[7] PavelPakshin, Julia Emelianova, Krzysztof Gałkowski, and Eric Rogers” Exponential Stability and Stabilization of nD Systems” 2015 IEEE 54th Annual Conference on Decision and Control (CDC) December 15-18, 2015. Osaka, Japan

[8] Xiaohui Zhang1, Dianrui Zhao2, Zhenying Pei2,Xiangming Zhang1, Chunyan Li1“Stability Criteria for A Class of Nonlinear Two-Dimensional Systems Via the Takagi-Sugeno Fuzzy Model” 978-1-4673-5534-6/13/$31.00_c 2013 IEEE, *25th Chinese Control and Decision Conference (CCDC).*

[9] Shyh-Feng Chen” Delay-Dependent Stability for 2-D Systems with Delays in the Roesser Model”, 2010 American Control Conference Marriott Waterfront, Baltimore, MD, USA June 30-July 02, 2010.

[10] Steffi Knorn and Richard H. Middleton”,Asymptotic Stability of Two -Dimensional Continuous Roesser Models with Singularities at the Stability Boundary” 51st IEEE Conference on Decision and Control December 10-13, 2012. Maui, Hawaii, USA

[11] LavenSoltanian and Michael Cantoni,” A 2-D Roesser model for automated irrigation channels and tools for practical stability and performance analysis”, 2012 Australian Control Conference.

[12] Shyh-Feng Chen and Wei-Yu Lee” Stability Analysis and Stabilization of 2-D Singular Roesser Models” 978-1-4577-2119-9/12/$26.00_c 2011 IEEE.

[13] Reza Babaloo, Mahdi Rezvani, and MasoudShafiee," BIBO Stability of Shift-Varying 2-D Systems Using Wave Model", 3rd International Conference on Control, Instrumentation, and Automation (ICCIA 2013), December 28-30, 2013, Tehran, Iran
[14] J. Velten, A. Kummert, A. Gavriilidis, K. Galkowski, "Application specific stability of 3-D Roesser-like model realizations", Multidimensional (nD) Systems 2015. nDS 2015. International Workshop on, September 2015.
[15] Y. Xiong, H. Cheng, G. Cheng, "A Roesser model based on multidimensional system in grid sensor network", 2015 IEEE 10th Conference on Industrial Electronics and Applications.
[16] M. G. B. Sumanasena, P. H. Bauer, "A Roesser model based multidimensional systems approach for grid sensor networks", Conf. Rec. 44th Asilomar Conf. Signals Syst. Comput. (ASILOMAR), pp. 2151-2155, 2010-Nov.
[17] M. G. B. Sumanasena, P. H. Bauer, "Realization using the Roesser model for implementations in distributed grid sensornetworks", Multidimensional Syst. Signal Process., vol. 22, no. 13, pp. 131-146, Mar. 2011.
[18] R. T.Wirski, "Synthesis of orthogonal Roesser model for two-dimensional FIR filters,"in International Symposium on Information Theory and its Applications (ISITA2010), Taichung-Taiwan, Oct. 2010.
[19] T. Hinamoto, A. Doi, W.-S. Lu, "Jointly optimal high-order error feedback and realization for roundoff noise minimization in 1-D and 2-D state-space digital filters", IEEE Trans. Signal Process., vol. 61, pp. 5893-5904, Dec. 2013.
[20] C. K. Ahn, "Overflow oscillation elimination of 2-D digital filters in the Roesser model with Wiener process noise", IEEE Signal Process. Lett., vol. 21, no. 10, pp. 1302-1305, Oct. 2014.
[21] C. El-KASRI1 and A. HMAMED2" Robust Reduced-order H1 Filter Design for Uncertain 2-D Continuous Systems with Time-varying Delays" Proceedings of the 3rd International Conference on Systems and Control, Algiers, Algeria, October 29-31, 2013.
[22] Cuihong Wang and Lin Jia"$H\infty$ Model Reduction for Positive 2-D Discrete Systems in Roesser Model", 978-1-4673-1398-8/12/$31.00 ©2012 IEEE.
[23] WANG Lanning1,2, WANG Weiqun2, CHEN Weimin2, ZHANG Guangchen2"Finite frequency fault detection observer design for 2-D continuous-discrete systems in Roesser model Proceedings of the 34th Chinese Control ConferenceJuly 28-30, 2015, Hangzhou, China".
[24] D. Meng, Y. Jia, J. Du, and F. Yu, "Data-driven control for relative degree systems via iterative learning," IEEE Transactions on Neural Networks, vol. 22, no. 12, pp. 2213-2225, Dec. 2011.
[25] P. Dabkowski, K. Galkowski, E. Rogers, Z. Cai, C. Freeman, P. Lewin, Z. Hurak, A Kummert, "Experimentally Verified Iterative Learning Control based on Repetitive Process Stability Theory", Proceedings of the American Control Conference, pp. 604-609, 2012.
[26] Yin Yanling, Bu Xuhui *, Yan Shuaike, Liu Jian"'Robust Quantized ILC design for Linear Systems Using a 2-D Model'978-1-4673-9714-8/16/$31.00c 2016 IEEE"
[27] Tamal Bose, Mei-Qin Chen, and RatchaneekornThamvichai,' Stability of the 2-D Givone–Roesser Model WithPeriodic Coefficients', IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS—I: REGULAR PAPERS, VOL. 54, NO. 3, MARCH 2007.
[28] Prashant Shah* ,HaranathKar, Vinaya Kumar Srivastava, 'Stability Analysis of 2-D PSV Filters described by FM-1 Model', *IEEE*.,978-1-4244-8165-1/11/$26.00 ©2011.
[29] K. Galkowski, "The Fornasini-Marchesini and the Roesser model : Algebraic methods for recasting", *IEEE Trans. Automat. Contr.*, vol. 41, pp. 107-112, Jan. 1996.
[30] Prashant k shah,'Stability analysis of 2-D PSV system represented by Givone–RoesserModel',under review