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FREQUENCY DOMAIN IDENTIFICATION OF SERVO SYSTEM WITH FRICTION FORCE USING ABC AND ANN TECHNIQUE

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ABSTRACT: Normally, most of the mechanical devices arrive with unnecessary nonlinearities. In servo system, the frequency domain system identification method is very difficult because of the presence of unnecessary nonlinearities. In the paper, hybrid technique is proposed for the frequency domain identification of servo system. The proposed hybrid technique is the combination of artificial neural network (ANN) and ABC algorithm. By using artificial network, the system parameters are produced at various mass levels, which are formed as a dataset. The ABC algorithm is used to optimize the system parameters from the dataset, which are pole, constant, DC gain and friction force etc. These optimized system parameters are given to the system and friction of the system is analyzed. The proposed method is implemented in MATLAB platform and the deviation performances are estimated. Moreover, the system parameters recognized by proposed method (ABC-ANN) is compared with actual system, hybrid technique, adaptive hybrid technique and PSO-ANN technique.

Keywords: Servo system, Nonlinearity, Friction, System parameters, ABC, ANN.

I. INTRODUCTION

System identification procedure exploits measured input-output to assess a model for capturing system dynamics [11] [16]. By removing mathematical models from corporeal systems, the objective and procedure of system identification [2] [4] is acquired. System recognition models can be erected for different stages and the control system can be sustained by optimally selecting their outputs [1]. Several appliances such as acoustic echo cancellation, channel equalization, biological system modeling and image processing have made known great apprehension in nonlinear systems identification [3] in current times. A few nonlinearity is present in hydraulic servo systems owing to friction force [8]. Due to the ability of servo systems to supply vast driving forces and rapid responses servo systems are often utilized in the position control of friction [6]. Position dependent friction happens [7] by generally using transmission mechanisms in raised precision systems that accomplish high-resolution movements. As a result, friction has an influence on each regime of operations of a servo system [9].

Friction is one of the most significant disadvantages in high accuracy servo systems [5]. The conflict practiced by a material in moving on top of another [12] [14] is recognized to be the frictional force. The friction force will perform by the velocity and period of contact [13]. The control of friction force on servo-systems is remarkable above all at low velocity motion [15]. Generally by means of transfer function [17] the frequency domain model of nonlinear systems can be signified. By the frequency domain technique, a waveform is examined presented in the waveform in regard to the varied frequency components [18]. The fabrication of nonlinear system can be erected using the frequency domain study of linear system [10]. The production frequency element is different from the giving frequency component for nonlinear system [20]. Frequency domain system recognitions trust the contribution and production signals to be intermittent or time controlled within the inspection time [19].

By the displace function in the bulk of the works, Frequency domain identification of servo system with friction force is controlled. As the transfer function target parameters of the plant are concluded at arbitrary, the control methods of such plants are uncreative and the friction force is bodily chosen. Thus the decided parameters are inappropriate and

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selection of friction force takes substantial time. System identification (SI) can be regarded as an optimization or minimization process from a computational point of analysis, in which the aim is to decide a model of a system so that its forecasted reply to a specified input is close sufficient to the assessed response from the actual system [21].

System identification consists of 2 tasks, such as the structural identification of the equations and estimation of the plant parameters. To assess the parameters of a system is the mission of system identification [22] [6]. Parameter estimation is a challenging mission and is usually prepared as an optimization problem [25]. Now, methodologies based on heuristic stochastic algorithms to work out the optimization problem in structural SI have been utilized in latest years: in particular, RLS, ARX methods, genetic algorithms (GAs), particle swarm optimization (PSO), ant colony optimization (ACO), artificial neural networks (ANN), evolutionary strategy (ES), and differential evolution (DE) algorithms have achieved increasing awareness [34] [21] [33]. On the other hand, most of the aforesaid techniques need a good initial guess of the parameters and a correct function gradient. Besides, difficulties take place by means of these techniques in the identification of large systems when only some measurement information is presented [21]. Due to the selection schemes applied and the neighbour production mechanism used within a short computation time, ABC includes a flexible and well-balanced mechanism to acclimatize to the global and local searching and utilization abilities consequently [23]. Hence, ABC algorithm looks for the system parameters from a particular range [22]. The chief benefit of ABC algorithm is easy, vigorous and competent to work out multi-variable, multi-modal and complicated combinatorial optimization problems [24].

In this document, we propose a hybrid method for servo system identification in the frequency domain to defeat this topic. The left over part of the text is designed as follows. The model of a servo system and the suggested method with essential mathematical are shown in Section 2, and the execution results are explained in Section 3 and Section 4 ends the paper.

II. SERVO SYSTEM MODEL

Generally a plant contains an actuator and some driving circuits, which are present in a servo system. Both of the components can be modelled as a second order transfer function, and the plant is driven by the actuator. The simplified system can be illustrated in Fig.1 The servo system contains two components namely, static friction and coulomb friction. The static friction is denoted as F_s^+ and F_s^- and the coulomb friction is specified as F_C^+ and F_C^-. The friction force of servo system is modelled based on the static or dynamic friction. The system can be decomposed into linear and non-linear blocks.

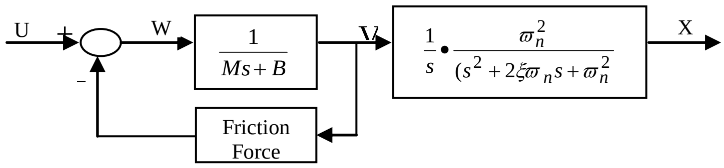

Fig. 1: Block diagram of simplified system with friction

By the long-established frequency-domain recognition techniques that are based on covariance study and Fourier transform, the plants to be recognized are forever supposed to be linear. However, this guess is approximately constantly worthless since the existence of friction. As, a plant can be signified by a linear block that explains the system dynamics in the feed forward path and a nonlinear block that illustrates the friction in the feedback path [2].

A. Process for Neural Network training

The training process of the neural network uses the back propagation algorithm, and the optimal dataset is trained well. An early investigated dataset is obtained from [2] and it is used as the training dataset D_s for neural network. The input of the dataset D_s is included in the excitation magnitude and the system parameters, poles, constants, DC gain, minimum friction force. The dataset D_s can be specified as

$$D_s = (m_1 \quad m_2) \ (P_0 \quad P_1 \quad .....P_{N_T-1}) \tag{1}$$

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From the above equation, m_1 and m_2 are the higher and lower excitation magnitudes and P_{N_T-1} is the system parameters. In fig.2, represents the feed forward network structure.

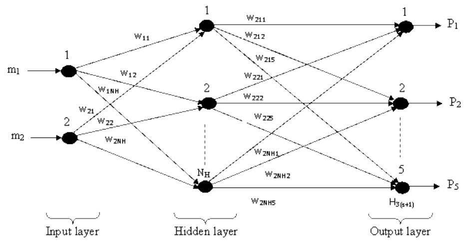

Figure 2: Structure of neural network.

Procedure of Back propagation training algorithm:

The arbitrary weights of hidden layer and the output layer neuron are generated in the specified interval $[w_{\min}, w_{\max}]$. For every neuron of the input layer weight is allocated with the unity value. Established the BP error by giving the training dataset D_s as input to the classifier as follows $E_v = P_{Target} - P_{out}$ (2)

From the above equation, P_{Target} and P_{out} is denoted as the target output and the network output, which is intended as $P_{out} = [P_0 \; P_1 \; P_2 \cdots P_{N_T-1}]$. Each output neuron of the network is represented as the elements of P_{out}, which can be defined as follows $P_j = \sum_{i=1}^{N_H} w_{ij} y_i$ (3)

where, $y_i = \frac{w_{1i}}{1+\exp(-m_1)} + \frac{w_{2i}}{1+\exp(-m_2)}; \quad 1 \le i \le N_H$ (4)

From the Eq. (3) & (4), N_H is specified as the number of hidden neurons, P_j is the output from j^{th} output neuron and w_{ij} is the weight of the $i-j$ link of the network. Then, y_i is the output of i^{th} hidden neuron. Also, find out the change in weights based on the obtained BP error as follows

$$\Delta w = \gamma . P_{out} . E_v \quad (5)$$

In Eq. (5), γ is the learning rate, usually it ranges from 0.2 to 0.5. Defined the new weights as follows,

$$w = w + \Delta w \quad (6)$$

Until BP error gets reduced to a least value, otherwise the process is repeated. Basically, the condition to be satisfied is $E_v < 0.1$. The well trained networks are obtained from the output of neural network process. Here, the input excitation magnitude is given, the suitable system parameters are provided by the well trained network. The detailed description of the parameter optimization using ABC algorithm is presented in the following section.

B. Optimal system parameters obtained by Artificial Bee Colony (ABC) Algorithm

In the section, the ABC algorithm is used to optimize the system parameters. From the network dataset, the system parameters are optimized. It is one of the optimization algorithms for solving the PQ problems. ABC algorithm consists of a set of possible solutions P_j (the population) that are represented by the position of the food sources. It consists of four phases, such as initialization phase, employed bee phase, onlooker bee phase and scout bee phase. The Pseudo code for ABC algorithm is given in the following section.

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Pseudo code for ABC algorithm
Begin
        Initialization
                Initialize the input parameters are poles, DC gain and friction force. The input parameter positions P_j are generated.
                Compute f(j) = min [ sum_{j=1}^{N} (P_actual^(j) - P_out^(j)) ] for each input parameters.
                Evaluate the fitness function of the each parameters F_j
While termination is not met
        Begin
                Employeed bee phase
                        Generate new solutions V_{i,j} for the system parameters and calculate F(j)
                        Apply the greedy selcetion process for optimal parameter selection
        End
        Calculate the probability p_j values of the system parameters.
        Begin
                Onlooker bee phase
                        Select a new solution depending on probability values of the poles, DC gain and friction parameters.
                        Evaluate the fitness function of the new parameter values.
                        Apply greedy selection process & obtain the optimal parameter value
        End
        Begin
                Scout bee phase
                        Determine the abandoned solution of the system parameter for the scout.
                                If abandoned solution exist
                                        Replace the abandoned solution with the new randomly produced system parameter
                                End if
                        Memorize the best system parameter
        End
Cycle=cycle+1
End while
End
```

Fig. 3: Pseudo-code of ABC algorithm for optimizing the system parameters

From the ABC algorithm, we can get the optimal control parameters for controlling the servo system. Then the performance analysis of the proposed approach is described in the following section

III. RESULTS AND DISCUSSION

The proposed method was implemented in MATLAB platform. The frequency domain of the servo system is recognized using the proposed (ABC-ANN) method. Here, the system parameters are established and implemented. These parameters are described in the first and third order servo system transfer functions and are given in the Eq. (12) and Eq. (13). The parameters are implemented using ABC algorithm with ANN technique and represented in Table I. The target data of system $G_1(s)$ and $G_2(s)$ network is trained. From the linear block, the input excitation magnitude and the output excitation magnitude are investigated. Moreover, the proposed method is compared with the actual system and the existing frequency domain identification methods, such as, hybrid technique, adaptive hybrid technique and PSO-ANN.

Table I: The parameters and their values utilized in the ABC-ANN technique.

S.No	Parameters	Values
1	$w_{\min}/w_{\max}$	0/1
2	Number of food sources	10
3	Maximum Number of Cycles (MCN)	50
4	Number of hidden layer	20

C. Experimental analysis of first order transfer function of servo system

The output performance of proposed ABC-ANN identification method is investigated in this section. Then the performance comparisons are illustrated in Fig. 4, 5, 6 and 7 respectively. By using Eq. (12), the system parameter of the proposed ABC-ANN technique is obtained and compared with the PSO-ANN method.

$$G_1(s) = \frac{10}{s+10} \qquad (12)$$

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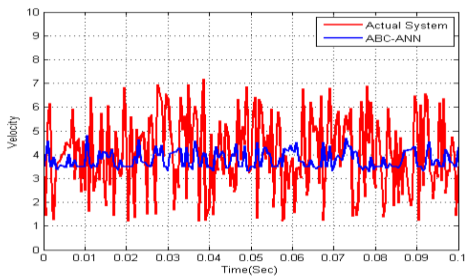

Fig. 4: The performance comparison of first order system output.

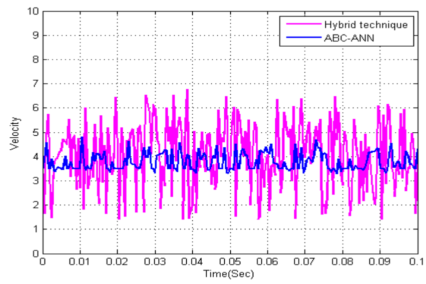

Fig. 5: The performance comparison of first order system output.

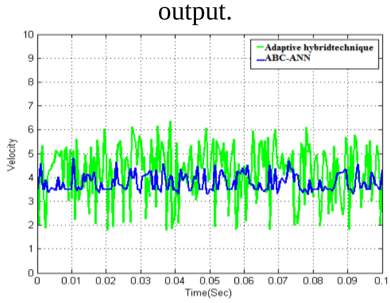

Fig. 6: The first order system output comparison performance.

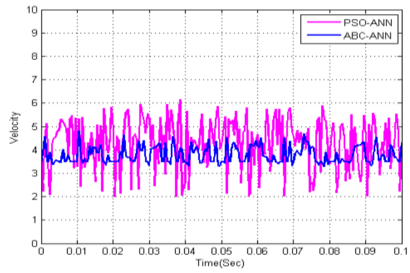

Fig. 7: System output comparison performance of from $G_1(s)$.

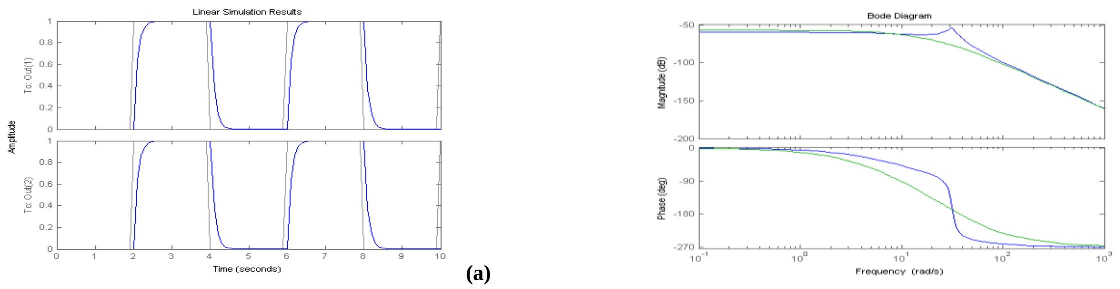

Fig. 8 (a, b): Linear simulation results for $G_1(s)$ output excitation magnitude to the linear block and bode plot for the $G_1(s)$ system with the given excitation magnitude

Here, the linear block result for the first order transfer function is represented as the output excitation magnitude. These output excitation magnitude for $G_{1(s)}$ is illustrated in the Fig. 8 (a). Then, the Bode plot for the identified system $G_{1(s)}$ with the given excitation magnitude and the proposed graph are illustrated in the Fig. 8(b). Moreover, it can be analyzed the computation time of the proposed system which can be compared with the actual system, hybrid technique, adaptive hybrid technique and the PSO-ANN method. The proposed method takes less time for computation process, when compared to the actual system, hybrid technique, adaptive hybrid technique and PSO-ANN methods.

Table II: The target and system parameters for the transfer function $G_{1\,(s)}$.

Parameters	Target	Existing technique [2]	Hybrid technique [26]	Adaptive hybrid technique [36]	PSO-ANN technique	Proposed ABC-ANN
N_T	5	5	5	5	5	5
$P_T^{(0)}$ (Pole)	-10	-10.1	-10.2	-10.0000	-10.0006	-10.0004
$P_T^{(1)}$ (Constant)	10	10.1	9.8	10.0000	10.0004	10.0002
$P_T^{(2)}$ (DC gain)	1	0.9	1.0	1.0000	1.0008	0.9999
$P_T^{(3)}$ $(F_c^{(+)})$	0.5	0.4	0.5	0.5	0.4995	0.5
$P_T^{(4)}$ $(F_c^{(-)})$	0.4	0.3	0.3	0.4	0.4	0.4

From the above table, the comparative result shows that, the proposed (ABC-ANN) method is providing the better identification of the parameters.

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D. Performance analysis of third order transfer function of servo system

In this section, the third order transfer function model is described. It can be analyzed by the system output from the ABC-ANN based system identification technique. Also, the performance of the proposed (ABC-ANN) identification method is compared with the actual system, hybrid system, adaptive hybrid technique and PSO-ANN technique. The performance comparisons are illustrated in Fig. 9, 10, 11and 12 correspondingly. The system parameters of the proposed and existing techniques are obtained from the Eq. (13). These obtained values are represented in table II.

$$G_2(s) = \frac{10000}{(s+10)(s^2+5s+1000)} \tag{13}$$

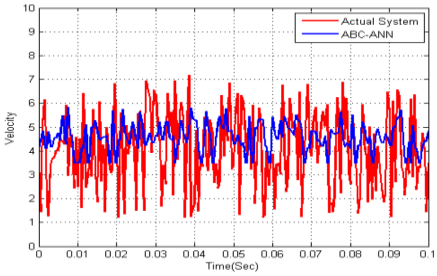


Fig. 9: The performance comparison of third order system output.

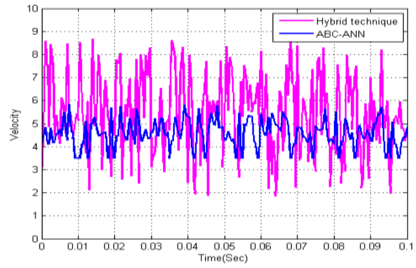


Fig. 10: The performance comparison of third order system output.

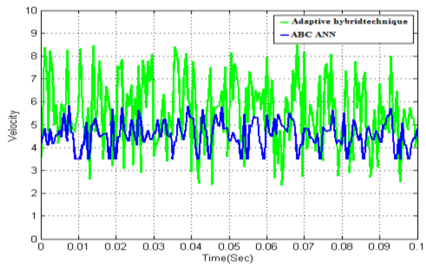


Fig. 11: The performance comparison of third order system output.

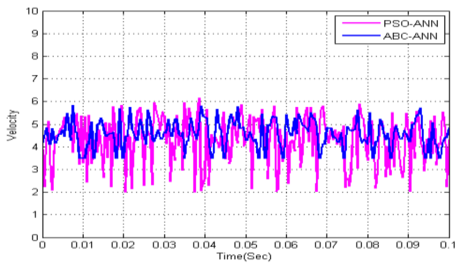
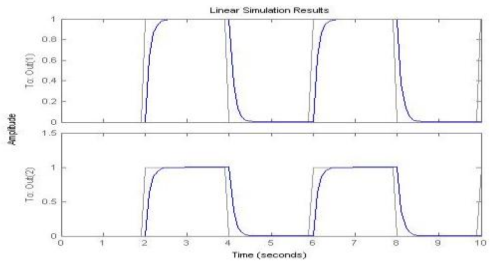
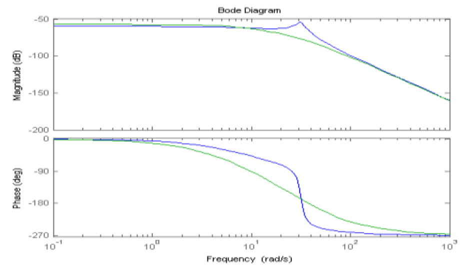


Fig. 12: The performance comparison of third order system output.



(a)



(b)

Fig. 13 (a, b): Linear simulation results for $G_2(s)$ output excitation magnitude to the linear block and bode plot for the $G_2(s)$ system with the given excitation magnitude.

The linear block result for the third order transfer function is represented as the output excitation magnitude. These output excitation magnitude for $G_2(s)$ is illustrated in the Fig. 13(a). Then, the Bode plot for the identified system $G_2(s)$ with the given excitation magnitude and the proposed graph are illustrated in the Fig. 13(b). In system II, analyzed the computation time of the proposed system which can be compared with the actual system, hybrid technique, adaptive hybrid technique and the PSO-ANN method. The proposed method takes less time for computation process, when compared to the actual system, hybrid technique, adaptive hybrid technique and PSO-ANN methods.

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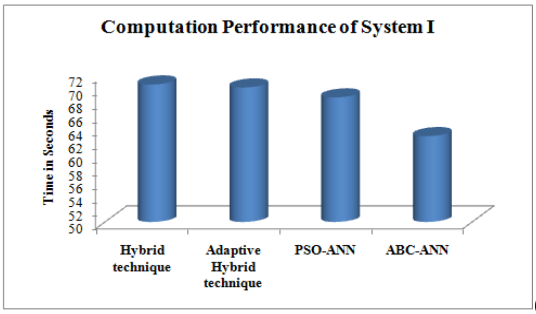
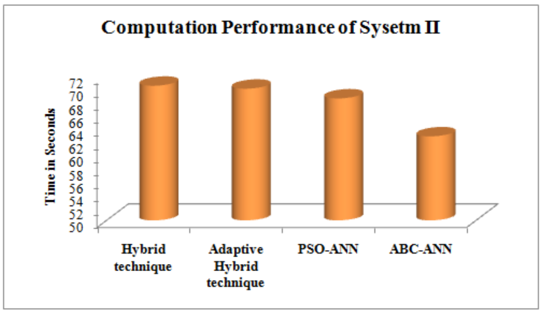
Table III: The target parameters, system parameters obtained for the transfer function $G_2(s)$.

Parameters	Target	Existing technique [2]	Hybrid Technique [26]	Adaptive hybrid technique [36]	PSO-ANN technique	Proposed ABC-ANN
N_T	6	6	6	6	6	6
$P_T^{(0)}$ (Root 1)	-2.5 +31.52i	-2.5714+30.525i	-2.5381+31.518i	- 2.5009 +31.5200i	-2.5004 +31.5143i	-2.5003+ 31.5213i
$P_T^{(1)}$ (Root 2)	-2.5-31.52i	-2.5714-30.525i	-2.5381-31.518i	-2.5011-31.5190i	-2.501-31.5034i	2.501-31.5032i
$P_T^{(2)}$ (Root 3)	-10	-10.1138	-10.0211	-10.0015	-10.0002	-10.0002
$P_T^{(3)}$ (DC gain)	1	0.9903	0.9989	1.0000	1.0000	1.0000
$P_T^{(4)}$ $(F_c^{(+)})$	0.5	0.4951	0.4968	0.4992	0.5000	0.5000
$P_T^{(5)}$ $(F_c^{(-)})$	0.4	0.3941	0.3957	0.4000	0.4000	0.4000



(a)



(b)

Fig. 14(a, b): Computational performance of proposed and existing methods in system I & system II

In the comparative analysis, the frequency domain identification parameters of the existing identification technique, hybrid technique, adaptive hybrid technique, PSO-ANN technique and ABC-ANN techniques are given in table II and III. The computation time for the hybrid, adaptive hybrid, PSO-ANN technique and the proposed method has been evaluated. Then the time complexity of the proposed method and the existing techniques are analyzed. In system I, the computation time of the proposed method is 62.851630 seconds. The computation time of the hybrid, adaptive hybrid and PSO-ANN methods are 70.587423, 70.136149 and 68.649127 seconds respectively. For system II, the computation time of the hybrid, adaptive hybrid, PSO-ANN and proposed methods are 72.158796, 71.959824, 69.568315 and 64.175593 seconds respectively. In system I and II, the computation performance of the proposed and existing methods are illustrated in Fig. 14(a, b). Therefore, the computation time is less for the proposed method which is compared to the other methods.

IV. CONCLUSION

In this paper, the ABC-ANN based identification technique was proposed and implemented. The output performances of the proposed method compared with the actual system, hybrid technique, adaptive hybrid technique and PSO-ANN. The proposed method optimizes the system parameter are enhanced, when compared to the other techniques. For analyzing the system I and II, the proposed method has less computation time which can be compared to the hybrid system, adaptive hybrid system and PSO-ANN methods. Therefore, the time complexity is reduced for the proposed system. Moreover, the deviation shows that, ABC-ANN method is performed well for identifying the servo system.

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