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Araştırma Makalesi / Research Article

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1. *INTRODUCTION (GİRİŞ)*

1. Derece tüm harfler büyük, bold, Normal, Türkçe bölüm başlıklarında parantez içinde ingilizcesi, ingilizce bölüm başlıklarında Parantez içinde Türkçesi verilmelidir. Türkçe çalışmalar için durum tam tersi olacaktır. Yazı tipi: Times N. Roman, 10 Pt., Normal, Satır Aralığı: Tam Aralık, Değer: 12, (Parantez içi 8 Pt., İtalik) Metin:Times N. Roman, 10 pt., Satır Aralığı: Tam Aralık, Değer: 12)

At the beginning of 1990s, the study of Carroll and Pecora [1] on chaos synchronization has initiated research on chaos–based communications. After [1], several aspects of communication applications of chaos were researched [2-4]. Since time delay increases the complexity of any system [5], it was observed that utilizing time delay in chaotic systems can grow better security in chaotic communication systems [6-10]. In [7], the delayed nonlinear feedback chaotik systems were considered and it was shown that signal encoding with such systems can be broken. In [9], the time-delay is assumed as a parameter to be estimated and an optimization method called chaotic ant swarm was used to estimate the time delay in the chaotic system and also other system parameters. In [10], synchronization between two different time-delayed systems is considered to construct a robust cryptosystem. This observation brought delay differential equation (DDE) based chaotic systems into secure communication where several rather simple chaos models were obtained [11-16]. Especially, in [11], Yalçın and Özoğuz presented a delay differential equation of which nonlinearity is based on a hard limiter function, to generate an n-scroll chaotic attractor. One special DDE is the Mackey–Glass delay differential model which was come across when modeling physiological systems [17-20].

Several research problems associated with DDE based chaotic systems were investigated. In [21], Tian and Gao designed a model reference adaptive controller for Mackey–Glass delay differential model where the delay was considered to be known. Wang et al. studied on designing a linear controller for time delay Lorenz systems [22]. In [23-25], researchers designed methods to extract messages masked in DDE based chaotic communication systems. Synchronization of chaotic systems with delay was addressed in [6, 26-30].

The focus of some of the previous research was devoted to cracking DDE based chaotic systems by estimating time delay. In [23-25], time series analysis methods were utilized to reconstruct DDE based chaotic system models. In [29], cross–correlation function based methods were fused with sliding mode observers to estimate time delay. In [9] and [31], Tang et al. investigated time delay estimation problem in DDE based chaotic systems and proposed a solution by converting it to an optimization problem where chaotic ant swarm and a differential evolution algorithm were used. In [7] and [8], Udaltsov et al. utilized time series analysis fused with different methods including auto–correlation function to estimate time delay. In [32], time delay and some other system parameters in time delayed chaotic systems were estimated by using optimization techniques. While satisfactory performance was obtained in these past works, all of these methods were offline where they were applied to a previously saved data.

Motivated by the currently available time delay estimation methods applied to DDE based chaotic systems being offline, in this work, we applied the method in [33] and [34] to estimate uncertain time delay online. This method considers the time delay as parameter which affects the system nonlinearly. The aforementioned is initiated via the design of a tuning function based observer signal for the state. The observer signal includes a sensitivity function based time delay estimation law. The tuning function in the state observer and the sensitivity function in the time delay estimator are the derived from a min–max optimization problem. The stability of the estimator is investigated in two sub–parts. In the first part, Lyapunov–type analysis is utilized to ensure the boundedness of all system signals under closed–loop operation. In the second part, convergency of time delay estimator is ensured providing that satisfaction of a nonlinear persistent excitation (PE) condition. The proof is based on showing that the time delay estimation error decreases by a finite number over every interval of time till it reaches to the vicinity of zero. Extensive simulation results are given to validate the estimation technique. Specifically, DDE based chaotic system models from [7-11] are borrowed and the performance of the time delay estimator is demonstrated.

**1.1. Delay Differential Equation based Chaotic System Model** *(Gecikmeli Türev Eşitliği Tabanlı Kaotik Sistem Modeli)*

2. Derece başlık Her kelimenin ilk harfi büyük, bold, Türkçe bölüm başlıklarında parantez içinde ingilizcesi, ingilizce bölüm başlıklarında Parantez içinde Türkçesi ve İtalik verilmelidir.

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In this study, we consider the following general model of scalar DDE based chaotic systems:

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| --- | --- |
|  | (1) |

(Eşitlikler, Eşitliklerin numarası eşitliğin karşısına sütun sonuna dayanmalı, word denklem aracı veya mathtype benzeri formül düzenleyicileri ile hazırlanmalı)

where  is state,  is the delayed state with  denoting the time delay, and  is a nonlinear function including state and delayed state. In the subsequent development, we will assume that state  and its past values are available, the structure of the nonlinear function  is known but the time delay  is uncertain.

There are several models that fit the general description in Eq. (1) [7, 31, 10, 11]. While, in this work, we focus on the general model and base our findings on it, we also present numerical studies on the following models which may be given as examples of Eq. (1). The model 1 is the time delayed logistic chaotic system which is given as [31]:

|  |  |
| --- | --- |
|  | (2) |

which shows chaotic behavior for . The second model is given as [11]:

|  |  |
| --- | --- |
|  | (3) |

for  a chaotic double–scroll attractor is observed in – plane. The third model is given as [7]:

|  |  |
| --- | --- |
|  | (4) |

where chaotic behavior is observed for . The fourth model is given as [10]:

|  |  |
| --- | --- |
|  | (5) |

where chaotic behavior is observed for . Following model assumptions are required by the subsequently designed time delay estimation method.

*Assumption 1*: The uncertain time delay  is bounded with respect to  with the region which is stated as  where  is known lower and  is known upper bounds, respectively. The nonlinear function  is either convex or concave in a region  of  that includes  (i.e. ).

*Assumption 2:*  is bounded and Lipschitz in time as follows

 (6)

where  is a Lipschitz constant. The function  is assumed to be Lipschitz wrt its arguments as

|  |  |
| --- | --- |
|  | (7) |

for some time–varying function  where  is a positive Lipschitz constant.

**1.1.1. Delay differential equation based chaotic system model** *(Gecikmeli türev eşitliği tabanlı kaotik sistem modeli)*

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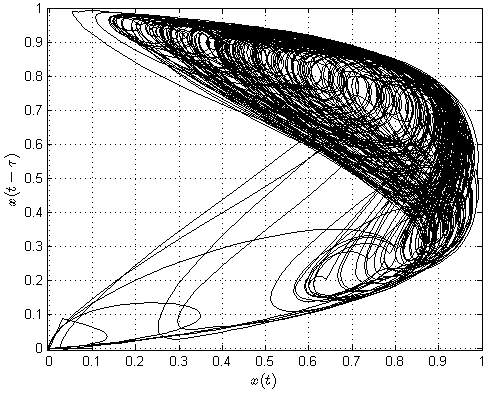


Figure 1. Chaotic behavior in phase plane of model (10 Pt)

*(Faz düzleminde kaotik davranış) (8 Pt)*

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