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Relax the chaos-model-based human behavior by electrical stimulation therapy design

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ABSTRACT

The brain's electrical activity is chaotic and unpredictable yet has a hidden order that is attracted to a certain region. There are numerous fractal strange attractors in the brain that change as thinking processes vary. Further, the thinking processes change the human behaviors, especially in schizophrenia or internet addiction. The proposed chaos modelling and control theory may offer useful and relevant information on electrical stimulation therapy design to change this thinking processes through stimulating the brain's electrical activities. The experimental result of relaxing body from a lots of electrotherapy clinics helps mental disorders relax the thinking chaos in mind to replace their chaotic behaviors from the brain's electrical activities. This paper tries to explain the above claim in the aspect of the electrotherapy and control theory to suggest the control signal of electrotherapy based on an assumption for chaos model of patient and its control signals design according to multiple stabilization solutions. In the future, the electrical stimulation therapy will be proof in the Raphael Humanistic Clinic or the other electrotherapy clinics.

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1. Introduction

Healthcare system includes physical and mental issues and has been a popular application area (Brailsford, 2016) by observing the modelling of human behavior (Daniel, 2014; Park, Kang, & Kim, 2014; Rosen, Whaling, Rab, Carrier, & Cheever, 2013) for more than sixty years. These papers (Daniel, 2014; Park et al., 2014; Rosen et al., 2013) propose the model of behavior as the internet use related to mental healthcare topic, but lack the therapy method to the kind of human behavior. The papers (Ives, 2004; Navarro & Arrieta, 2010) find out the chaos model in human, and the findings confirm the universality of chaotic behavior within human behavior which is caused by the brain's electrical activity. Moreover, numerous fractal strange attractors in the brain vary the thinking processes, and the proposed chaos control theory offers useful and relevant information on electrical stimulation therapy design to change the thinking processes related to the human behaviors. There is a paper (Sterman, 1988) introduces deterministic chaos in models of human behavior with methodological issues and experimental results. This paper focuses on chaotic model in which the simulated object in such model is human being (usually patient), and argue that this is an area where it is very important to capture behavior. This study proposes the control of electrical signal into human to depress the chaos in models of human behavior. It explains the effectiveness of electrotherapy control theory and how to fit into the scope of human behavior.

This study extends the idea of the fuzzy Lyapunov function (Tanaka, Hori, & Wang, 2003) to include chaotic model with uncertainty in the closed-loop control design with a differential term to overcome on these disadvantages of conservative theories with traditional Lyapunov function (single Lyapunov function) and single stabilization solution (Cao, Lam, & Sun, 1998, Cao, Rees, & Feng, 2000, Cao, Gao, Lam, Vasilakos, & Pedrycz, 2014; Chen, Tseng, & Uang, 1999; Joo, Shieh, & Chen, 1999; Liu, Sun, & Sun, 2005; Tanaka & Wang, 2001; Wong, Leung, & Tam, 1998; Yamamoto & Furuhashi, 2001) as piece-wise Lyapunov function (Feng, 2003). To relax the conservative constraint, design and analysis example of the chaotic system control problem is given to illustrate the effectiveness of the proposed parallel evolutionary approach and provide multiple stabilization solutions to be generate multiple

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electrical stimulation signals when compared with most existing nonlinear controllers (Alfi, 2012; Hashim & Abido, 2015, pp. 1–11; Lin, 2004). The controller designs of (Cao et al., 2014; Lam & Lauber, 2013; Lee, Park, & Joo, 2012, Lee, Joo, & Tak, 2014; Ou, Zhang, Yu, Guo, & Dang, 2014) which lack an extra term T_ρ are compared with the proposed controller which design is more general than the other papers (Cao et al., 2014; Lam & Lauber, 2013; Lee et al., 2012, 2014; Ou et al., 2014).

All these schemes are unnecessary conservative when the whole possible solutions are taking into consideration. An interesting contribution of (Hashim & Abido, 2015, pp. 1–11) used evolutionary algorithms (Lam, Leung, & Tam, 2003) to solve control parameters without the stability criterion. Although the problem of conservativeness can be avoided by this kind of searching approach, the required computing load and a lots of experiments (Hashim & Abido, 2015, pp.1–11) (The experiment means it is not a model-based simulation) may render the approach impractical, especially when a non-toy problem is encountered.

In the proposed design procedure, the design parameters are found by genetic algorithm (Chang, Chang, & Huang, 1999) for model-based simulation model with each trial solved by the LMI techniques with the stability criterion to avoid that model uncertainties deteriorate control performance significantly. Based on the fuzzy Lyapunov function approach and PDC scheme, sufficient conditions are proposed in this paper so that the closed-loop system is asymptotically stable.

2. Problem formulation and preliminaries

In the PDC scheme, both the nonlinear system to be controlled and the controller are represented as fuzzy combinations of the Takagi-Sugeno (T-S) fuzzy model. Each IF-THEN rule in the T-S fuzzy model of the plant represents local dynamics of the nonlinear system. Specifically, the j-th rule of the fuzzy model is of the following form:

$$\textbf{Rule j: IF } z_1(t) \text{ is } M_1^j \text{ and} \ldots \text{and } z_p(t) \text{ is } M_p^j \textbf{ THEN } \dot{x}(t) = A_j \bullet x(t) + B_j \bullet u(t), j = 1,2,\cdots L. \tag{1}$$

where$L$ is the number of the IF-THEN plant rules. In the rule, $z_1(t)$, $z_2(t)$, …, and $z_p(t)$ are the p premise variables, which can be state variables or functions of state variables, M_i^j is the fuzzy set corresponding to the i-th premise variable, $x(t)\in R^{n\times 1}$ is the state vector, and $u(t)\in R^{m\times 1}$ is the control input vector. In addition, $A_j(t)\in R^{n\times n}$ and $B_j(t)\in R^{n\times m}$ are system matrices and input matrices, respectively. Defining $\mu_i^j(\bullet)$ as the membership function corresponding to fuzzy set M_i^j, we have that $\mu_i^j(z_i(t))$ is the grade of membership of $z_i(t)$ accordingly. Using the sum-product composition, the firing strength of the j-th fuzzy rule can be calculated as $\prod_{i=1}^{p}\mu_i^j(z_i(t))$. The T-S fuzzy model is then inferred as the weighted average of the consequent parts:

$$\dot{x} = \frac{\sum_{j=1}^{L}\prod_{i=1}^{p}\mu_i^j(z_i(t))\cdot[A_j\cdot x + B_j\cdot u]}{\sum_{j=1}^{L}\prod_{i=1}^{p}\mu_i^j(z_i(t))} \equiv \sum_{j=1}^{L} h_j(z(t))\cdot[A_j\cdot x + B_j\cdot u], \tag{2}$$

where$h_j(z(t))$ is the normalized firing strength of the j-th rule and $z(t)\equiv[z_1(t),z_1(t),\ldots,z_p(t)]^T$. Furthermore, as $h_j(z(t)) \geq 0$ for all t, we have

$$h_j(z(t)) \geq 0,\ j = 1,2,\cdots,L,\ \text{and} \sum_{j=1}^{L} h_j(z(t)) = 1. \tag{3}$$

For the following derivations, we also require that $h_j(z(t))$'s are continuous and its time derivatives, $\dot{h}_j(z(t)) = \frac{d}{dt}h_j(z(t)) = \frac{\partial}{\partial z}h_j(z(t))\cdot\frac{\partial z}{\partial x}\cdot\dot{x}$, are well-defined. The assumption is easily satisfied by the functions commonly used to define membership functions, such as triangular, trapezoidal, Gaussian, and generalized bell functions. When there is discontinuity at the membership function derivatives, such as the tip of a triangular membership function, the value of the discontinuous point is defined as the mean value of its left and right neighbours.

Lemma 1. (Tanaka et al., 2003): If the time derivatives of $h_\rho(z(t))$ is well-defined, it can be represented as:

$$\dot{h}_\rho(z(t)) = \frac{\partial h_\rho(z(t))}{\partial z(t)}\cdot\dot{z}(t) = \sum_{m=1}^{2} w_{\rho m}(z(t))\cdot\mu_{\rho m}, \tag{4}$$

where $\sum_{m=1}^{2} w_{\rho m}(z(t)) = 1$ and $w_{\rho m}(z(t)) \geq 0$, with $\mu_{\rho 1} = \max_{z(t)} \dot{h}_\rho(z(t))$, $\mu_{\rho 2} = \min_{z(t)} \dot{h}_\rho(z(t))$.

That is, $\dot{h}_\rho(z(t))$'s are written as interpolation values of $\mu_{\rho 1}$ and $\mu_{\rho 2}$:

$$\dot{h}_\rho(z(t)) = w_{\rho 1}(z(t))\cdot\mu_{\rho 1} + (1 - w_{\rho 1}(z(t)))\cdot\mu_{\rho 2},$$

with $w_{\rho 2}(z(t)) = (1-w_{\rho 1}(z(t)))$. This relationship corresponds to the fact that any variable can be represented as linear interpolation of its two extremes. A detailed illustration can be found in the appendix of (Tanaka et al., 2003).

Based on the PDC scheme of (Tanaka et al., 2003), the corresponding fuzzy controller for the fuzzy system (2) can be formulated, assuming that the time derivative of $h_j(z(t))$ can be calculated, as follows:

$$u(t) = -\sum_{k=1}^{L} h_k(z(t))K_k x(t) - \sum_{\rho=1}^{L}\dot{h}_\rho(z(t))T_\rho x(t). \tag{5}$$

where

$K_k\in R^{m\times n}$ and the differential term of $T_\rho\in R^{m\times n}$ are constant control gain matrices to be determined. The closed-loop control system is then obtained by substituting (5) into (2):

$$\begin{aligned}\dot{x}(t) &= \sum_{j=1}^{L} h_j(z(t))\left[A_j x(t) + B_j u(t)\right] \\ &= \sum_{j=1}^{L}\sum_{k=1}^{L} h_j(z(t))h_k(z(t))\left[A_j - B_j K_k - \sum_{\rho=1}^{L}\dot{h}_\rho(z(t))B_j T_\rho\right]x(t).\end{aligned} \tag{6}$$

Taking model uncertainties into consideration, the T-S fuzzy model of the nonlinear system can be described as:

$$\dot{x}(t) = \sum_{j=1}^{L} h_j(z(t))\left[(A_j + \Delta A_j(t))\cdot x(t) + (B_j + \Delta B_j(t))\cdot u(t)\right], \tag{7}$$

where ΔA_j's and ΔB_j's represent the time-varying uncertainties corresponding to the system matrices and input matrices,

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