Type-2 Fuzzified Flappy Bird Control System

Atakan Sahin, Efehan Atici and Tufan Kumbasar
Control and Automation Engineering Department
Istanbul Technical University
Istanbul, Turkey
{sahinata, aticie, kumbasart}@itu.edu.tr

***Abstract*—In this study, we will present the novel application of Type-2 (T2) fuzzy control into the popular video game called flappy bird. To the best of our knowledge, our work is the first deployment of the T2 fuzzy control into the computer games research area. We will propose a novel T2 fuzzified flappy bird control system that transforms the obstacle avoidance problem of the game logic into the reference tracking control problem. The presented T2 fuzzy control structure is composed of two important blocks which are the reference generator and Single Input Interval T2 Fuzzy Logic Controller (SIT2-FLC). The reference generator is the mechanism which uses the bird's position and the pipes' positions to generate an appropriate reference signal to be tracked. Thus, a conventional fuzzy feedback control system can be defined. The generated reference signal is tracked via the presented SIT2-FLC that can be easily tuned while also provides a certain degree of robustness to system. We will investigate the performance of the proposed T2 fuzzified flappy bird control system by providing comparative simulation results and also experimental results performed in the game environment. It will be shown that the proposed T2 fuzzified flappy bird control system results with a satisfactory performance both in the framework of fuzzy control and computer games. We believe that this first attempt of the employment of T2-FLCs in games will be an important step for a wider deployment of T2-FLCs in the research area of computer games.**

Keywords—Type-2 Fuzzy Sets; Type-2 Fuzzy Logic Controllers, Games; Flappy Bird

I. INTRODUCTION

In the recent years, researchers have started giving more attention to computer games since they can be seen as ideal test-beds for the studies, especially for computational intelligence researches [1-11]. In this context, various games are handled and investigated such as Pacman [4], Scrabble [5], Super Mario [6] Counter-Strike [7], Unreal Tournament [8], Warcraft [9-10], TORCS (The Open Racing Car Simulator) [1, 11], and Flappy Bird [12-15]. The game "Flappy Bird" is a very popular in early 2014 [15-16]. Flappy Bird is a side-scrolling mobile game featuring 2D graphics. The main goal of the game is to control the bird's height while try to keep away from obstacles which are a series of pipes placed along the top and bottom of the screen [12-15]. The game formed the basis for several researches to achieve autonomously flying bird [13-15]. For instance, a bang-bang controller, which is designed by reinforcement learning in [13] and support vector machine in [14] is employed to the game. Moreover, a model predictive controller is implemented in [15].

Recently, we have witnessed that Type-2 (T2) Fuzzy Logic Controllers (FLCs) attracted significant research interest in various real-time control engineering applications [17-21]. Especially, it has been demonstrated that Interval T2 (IT2) FLCs achieved better control performances in comparison to their Type-1 (T1) counterparts due to the additional degree of freedom provided by the Footprint of Uncertainty (FOU) in their IT2-FSs [17-24]. Although the majority of the research work on IT2-FLCs focuses on the two-input structures [21-23], it has been shown in [24] that Single input IT2-FLCs (SIT2-FLCs) provide greater flexibility better functional properties and easy design.

In this study, we will present the novel application of the SIT2-FLCs to solve the obstacle avoidance problem of the flappy bird in the well-developed fuzzy control theory. To the best of our knowledge, our work is the first deployment of the widely used T2 fuzzy control structure to the computer games research area. We will present a novel T2 fuzzified flappy bird control system which is composed of two important blocks, namely the reference generator and SIT2-FLC. In these structures, the reference generator is the mechanism which gives the opportunity to handle the obstacle avoidance problem of the flappy bird game with providing reference tracking signal. It uses the bird's position and the pipes placed along the top and bottom of the screen to generate an appropriate reference signal to be tracked. Thus, a conventional fuzzy feedback control system can be defined. In this fuzzy control system, the main controller is the SIT2-FLC due to the fact that it can be easily tuned while it also provides a certain degree of robustness to system which cannot be accomplished by its T1 counterpart [24]. In this paper, we will firstly provide detailed information about the components of the proposed T2 fuzzified flappy bird control system. Then, we will present a simple design approach to tune the SIT2-FLCs and investigate its performance by providing comparative simulation results. Then, we will present experimental results performed in the game environment to show the efficiency of T2 fuzzy control system in comparison with its conventional counterpart. It will be shown that the proposed T2 fuzzified flappy bird control system results with a satisfactory performance both in the framework of fuzzy control and computer games.

The paper is organized as follows. Section II provides information about the game space of flappy bird. Section III presents the proposed T2 fuzzified flappy bird control system. Section IV gives the comparative simulation and experimental results; Section V presents conclusions and future works.

II. THE GAME SPACE OF FLAPPY BIRD

The original game "Flappy Bird" is a 2013 mobile game published by GEARS Studios [16]. The basic game logic of the game is as follows: Each time the player taps the screen, the bird flaps its wings, moving upward in an arc while gravity constantly pulls downward; if the screen is not tapped, the bird falls to the ground due to gravity, which also ends the game [12-16]. The main goal of the game is to control the bird's height while try to keep away from obstacles, i.e. the pipes. In this study, we will use the Matlab replica of the game Flappy Bird that can be downloaded from [25]. In this replica game, the parameters can be grouped as the pipe parameters $(p_g, \overline{p}_h, \underline{p}_h, p_s, p_w, H)$ and the parameters of the bird's dynamics (g, v, u) as shown on the game screen in Fig.1. These parameters are defined as follows [16]:

- **World height** (H) is the distance between the ceiling and the floor with a fixed value of 180 pixels.
- **Upper pipe height** $(\overline{p}_h)$ is the distance between the top of the upper pipe and ceiling. The maximum value of the height is assigned as 177 pixels and its value is generated by a uniformly distributed random number generator.
- **Pipe gap** (p_g) is the distance between the pipes which is fixed as 49 pixels.
- **Lower pipe height** $(\underline{p}_h)$ is the distance between the top of the lower pipe and floor. The value of the lower pipe height is defined as $\underline{p}_h = \overline{p}_h - 49$. Though, it is constrained with a minimum value as 36 pixels.
- **Pipe width** (p_w) is the width of the pipe with a fixed value of 24 pixels.
- **Pipe separation** (p_s) is the horizontal space between two consequent pipes with a fixed value of 80 pixels.
- **Gravitational constant** (g) is the acceleration constant of the bird in the y axis direction and has a default value assigned as 0.1356 pixels per frame.
- **Bird's x direction velocity** (v_x) has a fixed value of 1 pixel per frame.
- **Control signal** (u) is the binary input variable $u \in \{0,1\}$ provided by the user to flaps the bird and effects on the bird's y direction velocity (v_y) [14].

III. THE TYPE-2 FUZZIFIED FLAPPY BIRD CONTROL SYSTEM

In this section, we will present the proposed T2 fuzzified flappy bird control system which is shown in Fig. 2a. The proposed T2 fuzzy control system is composed of three main parts which are the reference generator, the SIT2-FLC, and the system dynamics of the bird.

A. *The System Dynamics of the Game*

As it has been asserted in the preceding section, the bird has a constant x-velocity whereas the y direction dynamics of the bird is controllable by the user through the control signal input which manipulates y-velocity of the bird. Therefore, in the rest of the paper, we will use the abbreviation v for representing v_y. The bird's system dynamics are defined as follows [14]:

$$y_t = y_{t-1} + v_t$$
$$v_t = \begin{cases} 2.5, & u = 1 \\ v_{t-1} - g, & u = 0 \end{cases} \quad (1)$$

where v_t and y_t are vertical velocity and vertical position of the bird at t^{th} frame, respectively. Here, u is the binary input signal that is generated by T2 fuzzy control structure.

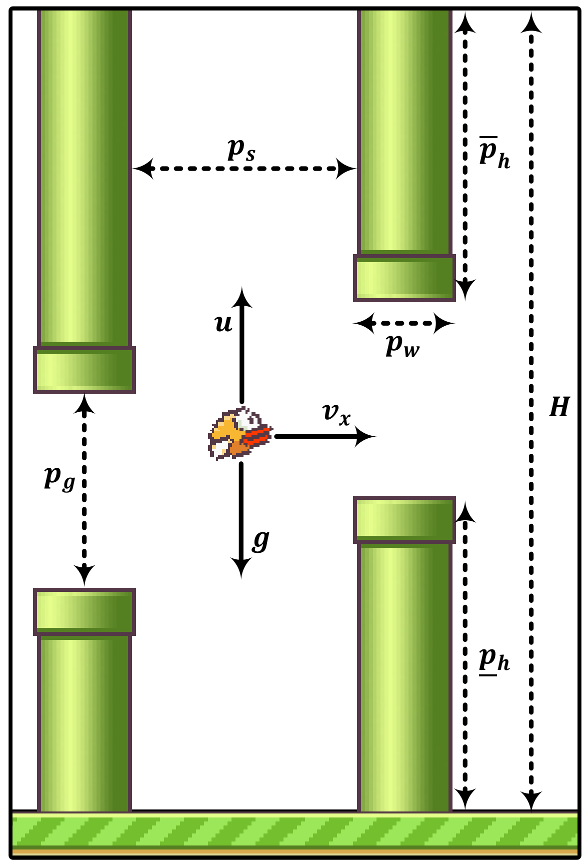

Fig. 1. Illustration of the game space

B. *The Reference Generator for the T2 Fuzzy Control System*

Here, the reference generator is described which transforms the obstacle avoidance problem of the flappy bird game to the reference tracking one. Thus, it gives the opportunity to construct fuzzy feedback control system. The reference generator provides the trajectory for the bird by taking account the gap between the pipes and the bird's position. The reference trajectory (r_i) is updated when the bird reaches the end of the pipe set (T_i) automatically as shown in Fig. 3. Then, the new reference trajectory is generated as follows:

$$r_{i+1} = \underline{p}_h + 0.3\left(\overline{p}_h - \underline{p}_h\right) \quad (2)$$

where i is the frame when the bird reaches the end of the pipe. The generation of the value r_{i+1} is sketched in Fig.2 in detail.

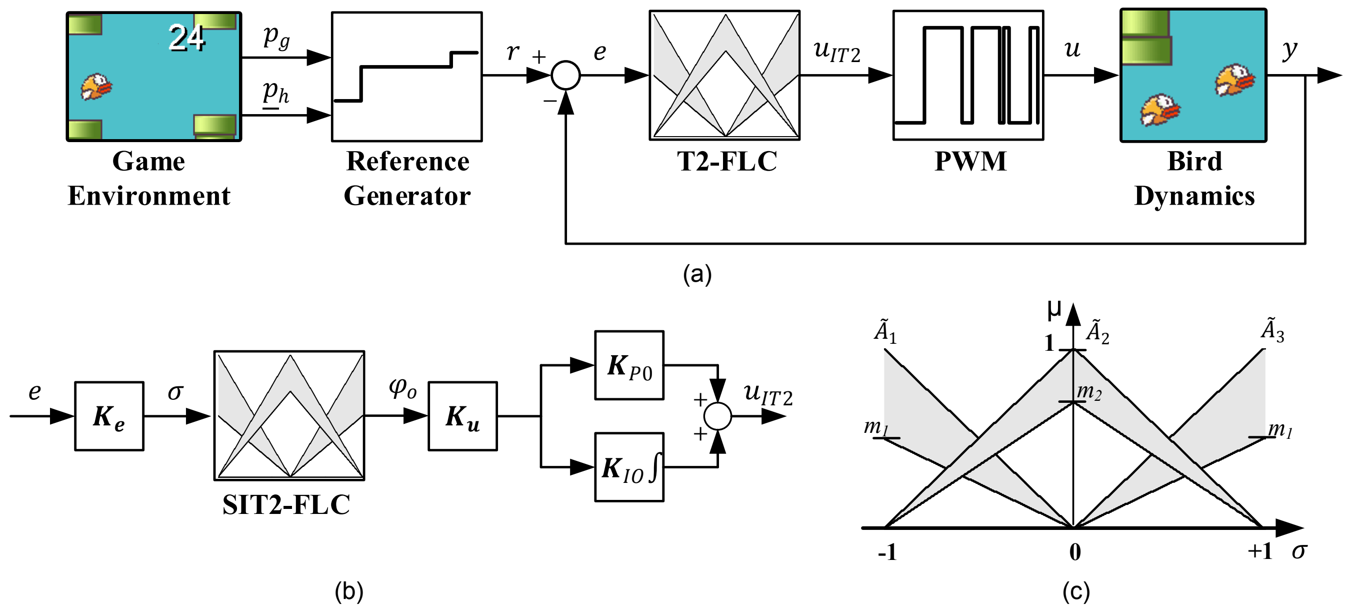

Fig. 2. Illustration of the (a) T2 fuzzified flappy bird control system (b) SIT2-FLC structure (c) antecedent IT2-FSs of the SIT2-FLC.

C. The Structure and the Design of the SIT2-FLC

In this subsection, we will firstly present the structure and then the design of the SIT2-FLC. The SIT2-FLC is constructed by choosing its input to be the error signal (e) and output as the control signal (u_{IT2}) as shown in Fig. 2a [24]. Here, the input Scaling Factor (SF) K_e is defined such that the input is normalized to the universe of discourse where the antecedent Membership Functions (MFs) of the SIT2-FLC are defined. Therefore, K_e is defined as:

$$K_e = \frac{1}{e_{max}} \tag{3}$$

where e_{max} is the maximum allowable error value [24]. The output of the SIT2-FLC (φ_o) is converted into the control signal (u_{IT2}) as follows:

$$u_{IT2} = K_P \varphi_o + K_I \int \varphi_o \tag{4}$$

where K_P and K_I are defined as:

$$K_P = K_{P0} K_u \quad K_I = K_{I0} K_u \tag{5}$$

Here, K_{P0} and K_{I0} are the baseline PI controller gains and K_U is the output SF defined as $K_u = {K_e}^{-1}$. It can be seen that, the SIT2-FLC is analogous to a conventional PI structure [24]. The continuous control signal (u_{IT2}) is then converted into a Pulse Width Modulation (PWM) generator, which is widely used in power electronics [26-28], into the input signal $u \in \{0,1\}$.

The rule structure of the SIT2-FLC is as follows:

$$R^n\text{: IF } \sigma \text{ is } \tilde{A}_n \text{ THEN } \varphi_o \text{ is } B_n\,, \qquad n = 1,2,3 \tag{6}$$

where B_n are the crisp consequents which are set as $B_1 = -1, B_2 = 0$ and $B_3 = 1$. The antecedent MFs are defined with triangular IT2-FSs $(\tilde{A}_n)$ as shown in Fig. 2b The IT2-FSs can be described in terms of upper MFs $(\overline{\mu}_{\tilde{A}_n})$ and lower MFs $(\underline{\mu}_{\tilde{A}_n})$ which create the FOU in IT2-FSs (the extra degree of freedom of the IT2-FSs) [17-24]. As shown in Fig. 2b, m_n's represent the height of the lower MFs and will be the main design parameters of the SIT2-FLC to be tuned. For the sake of simplicity, we will employ $m_2 = \alpha$ and $m_1 = m_3 = 1 - \alpha$. Thus, α is the new design parameter which determines the FOU in the antecedent IT2-FSs.

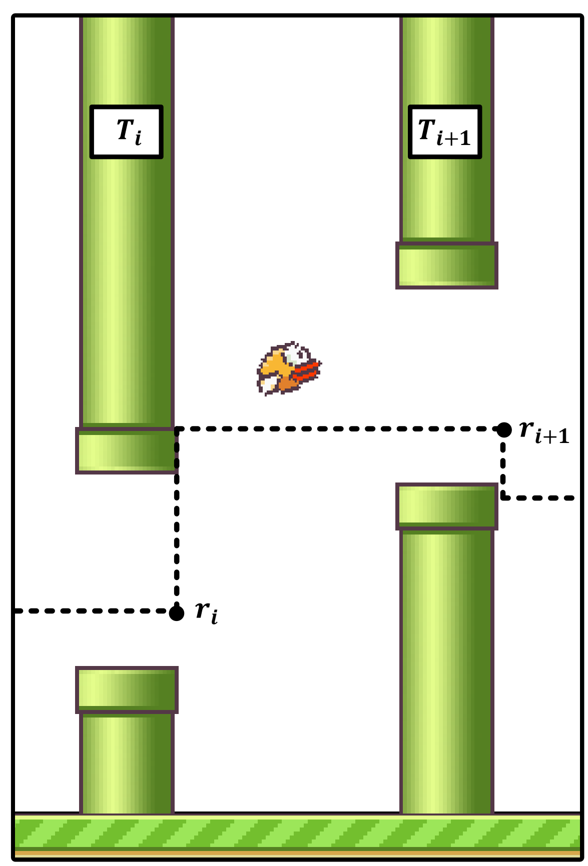

Fig. 3. Illustration of the reference generation

In [24], it has been demonstrated that input-output mapping of the SIT2-FLC ($\varphi_o(\sigma)$) can be derived for the input $\sigma \in [0,+1]$ as follows:

$$\varphi_o(\sigma) = \sigma \cdot k(\sigma) \tag{7}$$

and for the input $\sigma \in [-1,0]$ as follows:

$$\varphi_o(-\sigma) = -\sigma \cdot k(\sigma) \tag{8}$$

Here, $k(\sigma)$ is the T2 fuzzy gain and is defined as:

$$k(\sigma) = \frac{1}{2}\left(\frac{1}{\alpha + \sigma - \alpha\sigma} + \frac{-1+\alpha}{-1+\alpha\sigma}\right) \tag{9}$$

Thus, the only parameter to be tuned in (9) is the FOU parameter α [24]. Moreover, this simplifies the SIT2-FLC design method into a Control Curve (CC) generation, instead of a control surface design. In [24], by defining $\varepsilon_0(\sigma) = \varphi_o(\sigma) - \sigma$, the following design guidelines have been presented.

- If $0 < \alpha \leq \alpha_{c1}$, then $\varepsilon_0 < 0$ for $\forall\sigma \in \mathbf{O}_S$ where $\mathbf{O}_S \in [0,1)$ and $\alpha_{c1} = (3-\sqrt{5})/2$. Thus, a Smooth CC_{IT2} (S-CC_{IT2}) will be generated.
- If $\alpha_{c2} \leq \alpha < 1$, then $\varepsilon_0 > 0$ for $\forall\sigma \in \mathbf{O}_A$ where $\mathbf{O}_A \in [0,1)$ and $\alpha_{c2} = (\sqrt{5}-1)/2$. Thus, an Aggressive CC_{IT2} (A-CC_{IT2}) will be generated.

In Fig. 4, the S-CC_{IT2} and A-CC_{IT2} are sketched for the values $\alpha = 0.2$ and 0.8, respectively. Here, a Unit CC (U-CC) is sketched for the comparison. It can be clearly seen that the S- CC_{IT2} has relatively low input sensitivity when σ is close to "0" in comparison to the A-CC_{IT2}. Thus, the tuning parameter α of the SIT2-FLC can be tuned such that to enhance the control performance of its baseline counterpart with respect to the design guidelines [24].

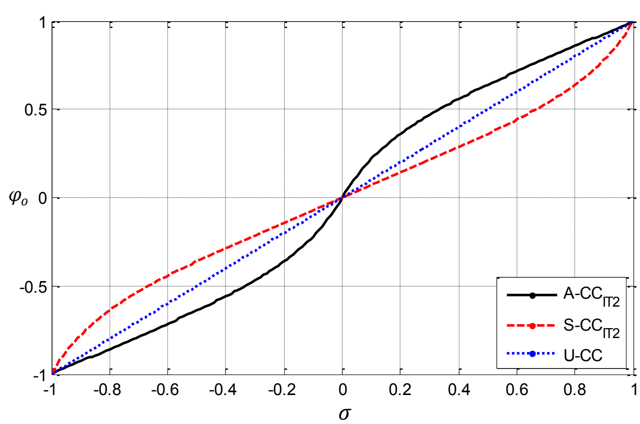

Fig. 4. Illustration of the S-CC_{IT2}, A-CC_{IT2} and U-CC

IV. Performance Evaluation of the Type-2 Fuzzified Flappy Bird Control System

In this section, we will present the design of the proposed T2 fuzzy control system and investigate its performance. We will firstly present two control system analyses in order to compare control performance of the SIT2-FLC in comparison with its baseline counterpart. Then, we will present experimental results that performed in the game environment to examine its game performance. The presented results are performed on a personal computer with an Intel Core I5 1.61 GHz processor, 4 GB memory, running Windows 7 64-bit Professional and Matlab R2014a.

A. Control System Performance Evaluation

In this subsection, we will present and examine the performance of the SIT2-FLC in the framework of fuzzy control theory. As it has been mentioned in the preceding section, the design of the SIT2-FLC is accomplished as an extension of its baseline counterpart. In this context, we will design firstly a conventional P controller, for the sake of simplicity, on a training trajectory which is generated randomly with respect to the game logic. Thus, the only parameter to be found is the proportional gain value (K_{p0}) through the genetic algorithm. The genetic algorithm provides the minimization of Integral of Time Absolute Error (ITSE). The ITSE is defined as follows:

$$\text{ITSE} = \int e^2(t)t\,dt \tag{10}$$

The optimal parameter value for the training trajectory is found as $K_{p0} = 5.04$. Then, to design a potentially more robust T2 fuzzy control system, the FOU parameter α of SIT2-FLC is set as $\alpha = 0.2$ which results with the S-CC_{IT2}.

The control performances of the designed structures are given in Fig. 5a while their corresponding ITSE values are tabulated in Table 1. It can be clearly seen the SIT2-FLC reduced the ITSE value by about 5% in comparison to its baseline counterpart in the training phase. Moreover, since the flappy bird system dynamics inherit nonlinearity as given in (1), we have tested the controller performances for a testing trajectory which is also generated randomly as shown in Fig. 5b. In other words, we have investigated the controller performances for different operating points at which they have not been designed. In comparison with its conventional counterpart, the SIT2-FLC resulted with a better tracking performance as shown in Fig. 5b. Besides, as it can be seen from Table I, the SIT2-FLC structure reduced the ITSE value by about 27% in comparison with the P controller on the testing trajectory.

TABLE I. Control Performance Evaluation

	ITSE	
	Training	*Testing*
P Controller	31630	136270
SIT2-FLC	30130	99674

It can be concluded that T2 fuzzified flappy bird control system resulted with comparatively good control performances in different operating points in comparison to its conventional counterpart. Moreover, with respect to the game logic; it is worth to underline at the reference variation (r_i) in the 1200th frame (the shaded area in Fig. 5b) that the conventional control system almost hit the T_{i+1} pipe which would end the game. On the other hand, for the same operation point, the T2 fuzzified flappy bird control system resulted with a satisfactory reference tracking performance.

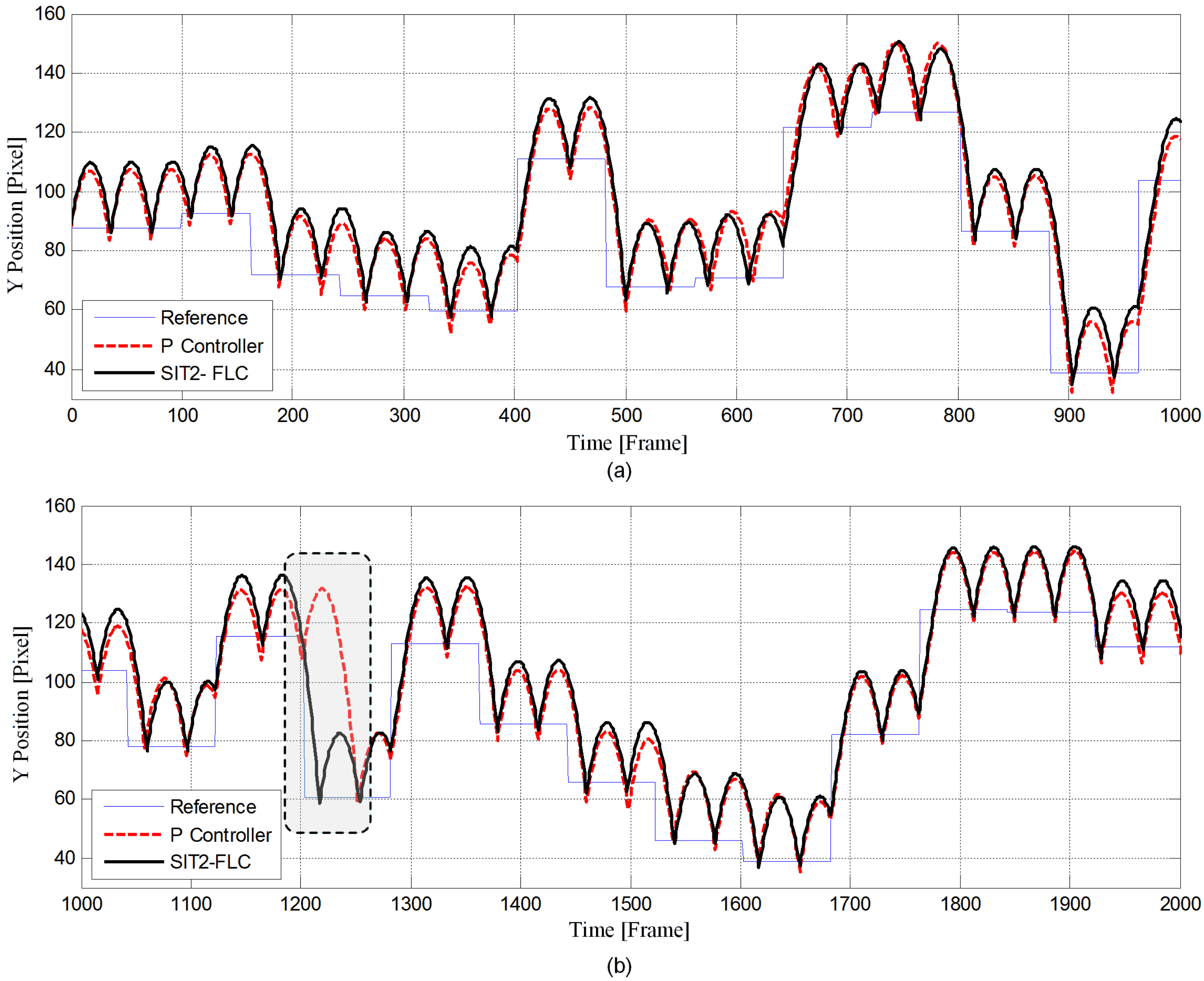

Fig. 5. System responses of the feedback control systems (a) for the training reference trajectory (b) for the testing reference trajectory

B. Game Performance Evaluation

In this subsection, we will examine the performance of the T2 fuzzified flappy bird control system with respect to the game logic. In the game, the number of successfully avoided pipes is the indicator of the score. Thus, since the game environment parameter $\bar{p}_h$ are generated randomly during the game, we have repeated each experiment 20 times and obtained the corresponding best and average scores of the experiments. We have also compared the proposed T2 fuzzified flappy bird control system with human players who are the authors of this paper and two of them are not expert players. The results of game performances are tabulated in Table II. It can be clearly observed that the T2 fuzzy control scheme improved the average score almost by 55% in comparison with its baseline counterpart.

It can be concluded that the game performance of the SIT2-FLC structure is better compared to its conventional and the authors' counterpart ones with respect to the game logic of flappy bird.

TABLE II. GAME PERFORMANCE EVALUATION

	Average	*Best*
Author-1	1	7
Author-2	16	84
Author-3	1	3
P Controller	112	423
SIT2-FLC	174	482

V. CONCLUSIONS AND FUTURE WORK

In this study, to the best of our knowledge, we presented the first deployment of the widely used T2 fuzzy control to the computer games research area. We proposed a novel T2 fuzzified flappy bird control system which is composed of two important blocks, namely the reference generator and SIT2-

FLC. The reference generator mechanism gave the opportunity to handle the problem as reference tracking one by using the bird's position and the pipes position to generate an appropriate reference signal to be tracked. Thus, we have constructed a conventional fuzzy feedback control system. In the fuzzy control system, to obtain a satisfactory tracking performance and to provide a certain degree of robustness to system, we have employed the SIT2-FLC structure which can be tuned in straightforward manner. We presented comparative simulation and experimental results. It has been shown that the proposed T2 fuzzified flappy bird control system results with a satisfactory performance both in the framework of fuzzy control and computer games.

We believe that this first implementation of T2-FLCs will be an important step for a wider deployment and development of T2-FLCs in the computer games research area. For our future work, we aim to extend the application area of T2 FSs and FLCs for the arcade-style games and first-person shooters.

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