# Fuzzy Logic Based Assessment on the Adaptive Level of Rehabilitation Exergames for the Elderly

Hao Zhang[†], Chunyan Miao[‡§], and Han Yu[‡]
[†]Interdisciplinary Graduate School (IGS), [‡]Joint NTU-UBC Research Centre of Excellence in
Active Living for the Elderly (LILY) and [§]School of Computer Science and Engineering (SCSE)
Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798
Email: i150001@e.ntu.edu.sg, {ascymiao, han.yu}@ntu.edu.sg

*Abstract*—**Rehabilitation exercises aim to help the elderly recover their deteriorating capabilities. Due to the advance in multimedia technologies, rehabilitation exergames are emerging and become more accessible for the elderly. Most existing exergames cannot adapt to specific individual's capabilities. In this paper, we propose a fuzzy logic based computational person-environment fit model to bridge this gap. As such, unprofessional personnel who are in charge of the assignments of the exergame sessions, such as volunteers in community centres, may learn the usefulness of the particular exergames to the individual elderly. We also provide case studies to analyze the adaptive level of three exergames for five elder Singaporeans to illustrate the application of our proposed model.**

## I. INTRODUCTION

Rehabilitation exercises aim to help the elderly recover lost capabilities and become as independent as possible. In order to recover efficiently and effectively, the elderly are advised to frequently repeat the recommended exercises. Traditional rehabilitation treatments are usually administrated on a one-to-one basis, which makes them difficult to scale due to the high cost and the dependency on human resources. In addition, it is time consuming for the elderly to travel to the clinics and they often feel isolated and bored during the treatments [1]. As a consequence, the adherence rate to traditional rehabilitation exercises is relatively low. Studies report that only 31% of prescribed exercises are completed, which reduce the effectiveness of traditional rehabilitation treatments [2].

For alternative modes to deliver rehabilitation exercises, literature has shown that exergames make the rehabilitation treatment more efficient and effective [3]. Exergames can decrease the monotony of repeated exercises and provide instant feedback on the elderly's motions [4]. Therefore, exergames have often been studied with elderly subjects to recover their physical and mental capabilities [5]–[7]. However, current rehabilitation exergames do not consider the usefulness and the adaptive level of a particular exergame to an individual elderly. It is not easy to suggest appropriate exergames to a specific individual, especially by non-professionals.

In this paper, we propose a fuzzy logic based system on rehabilitation exergames to autonomously assess their adaptive level to the individual elderly. Lawton and Nahemow [8] proposed the Person-Environment (P-E) fit model to evaluate the adaptive level of the surrounding environment to the elderly. Their model indicates that the adaptive level is determined by the interaction between an individual's competence and environment pressure, where competence refers to the capability of the elderly and environment pressure refers to environment obstacles to the elderly. The P-E fit model has been proven of its usefulness on adaptive level assessment [4], [9], [10]. However, prior studies on P-E fit model mainly focus on the physical environment and majority of them only conduct qualitative analysis. Therefore, we proposed the Computational P-E Fit model (CoPEF) to obtain quantitative results in a virtual game environment [11]. In this paper, we apply fuzzy logic to improve the CoPEF model and obtain the specific adaptation scores for an exergame to each individual elderly. In the fuzzy logic system, we quantify the barriers in exergames, elderly's functional limitations in playing the exergames, and their interactions. The proposed fuzzy logic based method computes the adaptive level using above information. According to Lawton's opinion, both excessively high and excessively low environment press lead to low adaptive level to the individuals [12]. We leverage this observation as source of the fuzzy rules. To evaluate the fuzzy logic system, we conduct case studies to assess the adaptive level of an exergame to five elderly user in Singapore over a one-month period. The results show that the prediction is consistent with the tendency of players' performance.

## II. RELATED WORK

Exergames for rehabilitation offer a sense of self-determination, provide a feeling of independence, and improve the quality of life of the elderly [13]. Because exergames are relatively new for the majority of the elderly, some researchers focus on increasing elderly's interests on exergames. Balaam *et al.* found the evidence that entertainment-oriented video games are useful for stroke rehabilitation [14]. Moreover, Alankus *et al.* found that motion-based games, which combine motion-detection with fun in the video games, can motivate people to exercise with the games voluntarily [4]. The engagement created in the rehabilitation games can make the elderly feel more enjoyable [15].

Prior research does not consider the effectiveness of the exergames to individual elderly. Hence, we apply the P-E fit model in the virtual game environment. In the original P-E fit theory proposed by Lewin [16], the ecological equation

$B = f(P, E)$ is used to characterize the common effect between the state of person $P$ and the surrounding environment $E$, where $P$ denotes the personal competence and $E$ denotes the environment press. Based on Lewin's theory, Lawton *et al.* added an interactive term $P \times E$ into the ecological equation: $B = f(P, E, P \times E)$, to account for the behaviors affected by the interaction between an individual's competence and environmental pressure [8], [12]. Iwarsson *et al.* applied the P-E fit model to evaluate the adaptive level of the surrounding environment to the elderly [9], [17]. They found that the fitness between the elderly's competence and environment conditions is important [18]. In order to age well, the environment assessment is important to better understand the relationship between the person and the environment press [19].

## III. FUZZY LOGIC BASED ASSESSMENT

Inspired by prior work applying the P-E fit model in the physical environments [17], [18], we propose the fuzzy logic based assessment to quantitatively evaluate the adaptive level of the exergames to elderly. The assessment consists of four steps: the first two steps require us to identify the barriers of the exergames and the individual's functional limitations. The third step is to obtain the interaction between these barriers and limitations. Lastly, the proposed fuzzy logic technique is used to compute the adaptive level.

### *Step 1. Assessment of barriers in exergames*

This assessment quantifies the barriers hindering the elderly from playing the exergames, which corresponds to the environment press in the conventional P-E model. Prior studies proposed the criteria of motion and interface design in exergames, which can be used to identify barriers in various exergames [20]–[22]. Besides the barriers within the exergames, we also consider the surrounding physical environment that may hinder the elderly from playing the exergames [9]. We summarize these criteria into 31 barriers which may prevent the elderly from playing the exergames. The 31 barriers can be categorized into the following groups:

1) **External environment:** B1) narrow space to play; B2) uneven floor; B3) pool lighting; B4) visual distraction of player's attention, and; B5) slippery surface.
2) **Cognition:** B6) cognitive challenge; B7) no appropriate feedback; B8) new knowledge to learn, and; B9) insufficient time when waiting for responses.
3) **Audio:** B10) no audio signal when game states change; B11) background noise; B12) synthetic speech; B13) binocular hearing, and; B14) high frequency tones (over 1000 Hz).
4) **Visual:** B15) no visual signals when game states change; B16) abstract design of markings and signs; B17) poorly exposed markings and signs; B18) small elements on a display; B19) complex interface; B20) lack of luminance contrast; B21) lack of color contrast; B22) peripheral vision required, and; B23) moving interface elements.
5) **Motion:** B24) required to turn wrist; B25) both hands required; B26) feet movements required; B27) finger movements required; B28) illogical controls; B29) operations required at the corners; B30) sudden movements involved, and; B31) required to move persistently.

The detailed information of the exergames should be provided by the game developers. We quantify the severity of the barriers in a given exergame by assigning the scores from zero to three, in accordance with the previous work done by Iwarsson and Isacsson [9]. If we denote the score of the $i$th barrier as $S_{Bi}$, then we can write $S_{Bi} \in \{0, 1, 2, 3\}$, where $i = 1, 2, \ldots, 31$. A higher score denotes a more serious barrier and zero means the absence of this barrier.

### *Step 2. Assessment of functional limitations*

Senior citizens tend to suffer from motor and cognitive impairments. However, the degree of impairments may differ with each individual. To obtain the elderly's competence of playing exergames, we need to assess their functional limitations. From prior studies on how the elderly interact with physical environments [9] and virtual environments [20], [23], we identify 13 major functional limitations of the elderly. These limitations can be categorized into the following two groups:

1) **Physical functional limitations:** L1) poor balance; L2) incoordination; L3) poor stamina; L4) difficulty in moving head; L5) reduced upper extremity function; L6) reduced spine or lower extremity function; L7) reduced fine motor skill; L8) dependency on walking aids, and; L9) dependency on wheelchair.
2) **Perception and cognition limitation:** L10) difficulty in information interpretation; L11) decrements in episodic memory; L12) visual impairment, and; L13) auditory impairment.

Based on known health conditions of each individual elderly, we imitate the procedure in Step 1 to score the severity of their functional limitations. If we denote the score of the $j$th limitation of an elderly individual as $S_{Lj}$, then we can write $S_{Lj} \in \{0, 1, 2, 3\}$, where $j = 1, 2, \ldots, 13$. If an individual does not suffer from the $j$th functional limitation, $S_{Lj} = 0$. On the other hand, a higher score represents a more serious functional limitation.

### *Step 3. Assessment of interaction*

According to the original P-E model, computation of the adaptive level requires understanding the interaction between the individual's limitations and the barriers in the exergames. Hence, we indicate the barriers which may hinder the elderly with corresponding limitations from playing the exergames, which are shown in Table I. If we denote the interaction score of $i$th barrier and $j$th limitation as $S_{I(i*j)}$, then the $S_{I(i*j)} = S_{Bi} \times S_{Lj}$, only when the interaction is displayed in Table I.

### *Step 4. Fuzzy logic computation*

The input for the fuzzy logic system is a 3-tuple, denoted as $< x_1, x_2, x_3 >$, where $x_1 = \sum_{i=1}^{31} S_{Bi}$, $x_2 = \sum_{j=1}^{13} S_{Li}$,

Fig. 1. An elderly player is playing the Virtual Table Tennis exergame.

$x_3 = \sum_{i=1}^{31}\sum_{j=1}^{13} S_{I(i*j)}$. Each input ($x_i, i = 1, 2, 3$) is associated with three fuzzy sets: high (H), medium (M) and low (L). We apply Gaussian membership function (MF) [24] to compute $x_i$, which is expressed as:

$$\mu_{X_i^d}(x_i) = e^{-\frac{x_i - \bar{x}_i^d}{\sigma_i^d}}, \tag{1}$$

where $X_i^d$ ($i = 1, 2, 3$ and $d =$H, M, L) is a fuzzy set, $\bar{x}_i^d$ and $\sigma_i^d$ are the mean and standard deviation values for the corresponding Gaussian MF. The result $\mu_{X_i^d}(x_i)$ denotes what extent $x_i$ belongs to $X_i^d$. For output $y$ (Adaptive Level), we associate five fuzzy sets with it: very high (VH), high (H), medium (M), low (L), and very low (VL). The MF for the five fuzzy sets are:

$$\mu_{Y^d}(y) = e^{-\frac{y - \bar{y}^d}{\sigma_y^d}}, \tag{2}$$

where $d =$ VH, H, M, L, VL. $\bar{y}^d$ and $\sigma_y^d$ are the mean and standard deviation values for different MF.

TABLE I
PARTIAL-RESTRICTION INTERACTIONS

| **FT*** | **Barriers with interactions** |
|---|---|
| L1 | B1, B2, B3, B5, B23, B25, B26, B29, B30, B31 |
| L2 | B1, B2, B5, B23, B25, B29, B30, B31 |
| L3 | B2, B5, B8, B10, B15, B29, B31 |
| L4 | B3, B17, B20, B22, B23, B29, B30 |
| L5 | B24, B25, B27, B29, B31 |
| L6 | B26, B29, B31 |
| L7 | B24, B25, B27, B29 |
| L8 | B1, B2, B3, B5, B10, B15, B25, B26, B29, B30 B31 |
| L9 | B1, B2, B3, B5, B10, B25, B26, B29, B30 |
| L10 | B3, B4, B6, B7, B8, B9, B10, B11, B12, B13 B14, B16, B17, B18, B19, B20, B21, B22, B28, B30 |
| L11 | B4, B6, B7, B8, B9, B10, B11, B12, B13, B14 B15, B16, B19, B20, B22, B23, B28, B30 |
| L12 | B2, B3, B4, B5, B10, B11, B12, B13, B14, B16 B17, B18, B19, B20, B22, B23, B28, B29 |
| L13 | B3, B11, B12, B13, B14, B15, B17, B19, B20, B21 |

*FT denotes the functional limitation.

TABLE II
RULES FOR THE FUZZY SYSTEM

| Rules | $x_1$ | $x_2$ | $x_3$ | $y$ | Rules | $x_1$ | $x_2$ | $x_3$ | $y$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | H | H | H | VL | 2 | H | H | M | M |
| 3 | H | H | L | M | 4 | H | M | H | L |
| 5 | H | M | M | H | 6 | H | M | L | M |
| 7 | H | L | H | M | 8 | H | L | M | VH |
| 9 | H | L | L | L | 10 | M | H | H | L |
| 11 | M | H | M | H | 12 | M | H | L | M |
| 13 | M | M | H | M | 14 | M | M | M | VH |
| 15 | M | M | L | M | 16 | M | L | H | M |
| 17 | M | L | M | H | 18 | M | L | L | L |
| 19 | L | H | H | M | 20 | L | H | M | VH |
| 21 | L | H | L | M | 22 | L | M | H | M |
| 23 | L | M | M | H | 24 | L | M | L | L |
| 25 | L | L | H | M | 26 | L | L | M | M |
| 27 | L | L | L | VL | | | | | |

According to the initial P-E fit model [8], we define 27 rules for the fuzzy logic system as shown in Table II. After defining the fuzzy sets and rules, the product inference engine for a real-value point $x^* =< x_1^*, x_2^*, x_3^* >$ is displayed as follows:

$$\mu_{Y'}(y) = \max_{l=1}^{M}[\prod_{i=1}^{3} e^{-(\frac{x_{iP}^l - \bar{x}_i^l}{\sigma_i^l})^2} e^{-(\frac{x_{iP}^l - x_i^*}{a_i})^2} \mu_{Y^l}(y)], \tag{3}$$

where

$$s_{iP}^l = \frac{a_i^2 \bar{x}_i^l + (\sigma_i^l)^2 x_i^*}{a_i^2 + (\sigma_i^l)^2}, \tag{4}$$

for $i = 1, 2, 3$. $a_i$ is the factor to suppress noise, which is much larger than $\sigma_i^l$. $M$ is the number of rules. $\bar{x}_i^l$ and $\sigma_i^l$ are the mean and standard deviation values of the Gaussian MF corresponding to the fuzzy set of $x_i$ in the $l$th rule. $Y^l$ is the fuzzy set of output $y$ in the $l$th rule. Then, we apply the center average defuzzifier [24] to transform the output fuzzy set $Y^{'}$ to a real value $y^*$ as follows:

$$y^* = \frac{\sum_{l=1}^{M} \bar{y}^l \omega_l}{\sum_{l=1}^{M} \omega_l}, \tag{5}$$

where $\bar{y}^l$ is the center of output fuzzy set in the $l$th rule, and $\omega_l$ is its height obtained from Eq. 3. $y^*$ is considered to be the predictor of the adaptive level, where higher values of $y^*$ represents higher adaptation.

TABLE III
PARAMETERS OF FUZZY LOGIC SYSTEM

| $d$ | VH | H | M | L | VL |
|---|---|---|---|---|---|
| $\bar{x}_1^d$ | - | 50 | 30 | 10 | - |
| $\sigma_1^d$ | - | 10 | 10 | 10 | - |
| $\bar{x}_2^d$ | - | 23 | 14 | 5 | - |
| $\sigma_2^d$ | - | 5 | 5 | 5 | - |
| $\bar{x}_3^d$ | - | 260 | 170 | 80 | - |
| $\sigma_3^d$ | - | 50 | 50 | 50 | - |
| $\bar{y}^d$ | 1 | 0.8 | 0.5 | 0.2 | 0 |
| $\sigma_y^d$ | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |

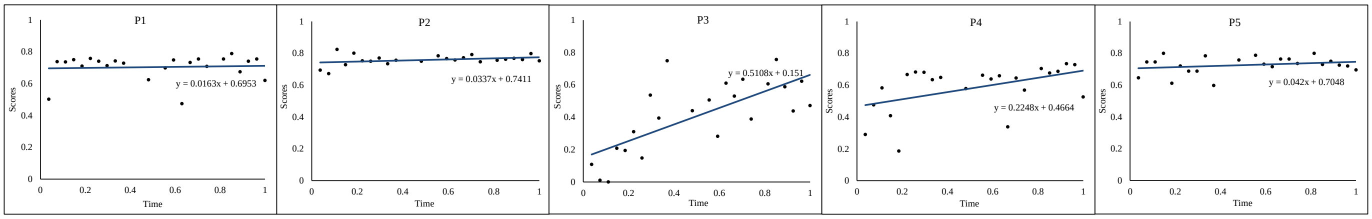

Fig. 2. Participants' performance comparison in Virtual Table Tennis.

TABLE IV
INPUTS AND ADAPTIVE LEVEL RESULTS FOR EACH PARTICIPANT

| | Gender | Age | $x_1$ | $x_2$ | $x_3$ | $y^*$(AL) |
|---|---|---|---|---|---|---|
| P1 | M | 75 | 32 | 10 | 30 | 0.375 |
| P2 | F | 63 | 32 | 9 | 70 | 0.374 |
| P3 | F | 57 | 32 | 16 | 137 | **0.626** |
| P4 | F | 66 | 32 | 13 | 166 | **0.755** |
| P5 | F | 63 | 32 | 10 | 75 | 0.406 |

## IV. EMPIRICAL EVALUATION

The Joint NTU-UBC Research Centre of Excellence in Active Living for the Elderly (LILY), Nanyang Technological University, Singapore, has initiated a number of interactive rehabilitation exergames using Kinect as the non-intrusive motion detection device. Virtual Table Tennis (VTT) offers elderly an enjoyable interactive environment for physical exercises and cognitive training. Specifically, it provides an augmented reality of playing table tennis (see Fig. 1). VTT requires the elderly repetitively identify and hit the appropriate balls. These repetitive motor and cognitive activities are beneficial to prevent various diseases of aging. Various game playing data namely game scores, hand movements, and positions are captured non-intrusively. We have recruited five elderly to play the VTT exergame for preliminary assessment of the usability and effectiveness of the game. While playing the VTT exergames for 26 days, all the five subjects considered it exciting and interesting.

Table III presents the mean and standard deviation values for the Gaussian MFs associated with the fuzzy sets. After the input values for each participant pass through the fuzzifier and fuzzy inference engine, the specific output values of adaptive level will be obtained by going through the defuzzifier. The inputs for each participant and the computed adaptive level results in the empirical evaluation are shown in Table IV. From the results of the fuzzy system we can identify that the adaptive level of P1, P2 and P5 are relatively low. The results of P3 and P4 are higher than 0.6, which suggests the exergame is appropriate and effective for them to play. Fig. 2 shows the trend of game scores obtained by each participant, in which we can find the scores of P1, P2, and P5 remains relatively stable. However, the scores of P3 and P4 exhibits significant rise. Subsequently, we perform the linear regression for each participant to analyze their performance in the 26-day playing. If we consider the slope $k$ as the reflection of effectiveness for the exergame to the elderly, we find the $k$ values for P1, P2 and P5 are less than $0.05$. However, the $k$ values for P3 and P4 are $0.51$ and $0.22$, which reflect their improvements in playing VTT. This slope $k$ value indicates that the empirical findings are consistent with our predictions that VTT will be more beneficial to P3 and P4. The fact that the predictions are in line with the empirical studies demonstrates the usefulness of the fuzzy logic based assessment. Since the individual elderly may suffer from different functional limitations, as non-professionals, we can rely on this assessment to determine appropriate exergames for them to play and perform rehabilitation exercises.

## V. CONCLUSION AND FUTURE WORK

Exergame can motivate the elderly to take exercises and keep healthy, which is proven to be effective and efficient in rehabilitation. Therefore, exergame design is an active research area in recent years. In our study, we define the fuzzy logic based assessment to help the non-professionals to find the adaptive level of the exergames to individual elderly, and then to recommend the appropriate exergames to the elderly to play. We conducted empirical studies to evaluate the adaptive level of the VTT exergame to five elderly players. Empirical results are consistent with the predictions, which indicates the effectiveness of our approach.

In future work, we prepare to improve the validity of the assessment by conducting more user studies on various exergames. Besides the adaptive level, we found the attractiveness of the exergames is also influential in elderly's rehabilitation. One direction of our future work is to identify the aspects of the exergames to attract elderly. For example, we found the familiar virtual environment has positive effects when the elderly interact with it [25]. Thus, we identify another research opportunity to discover which factors may influence elderly's motivation in virtual environments.

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