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Auto-Hierarchical Data Algorithm: Focus on Increasing Users' Motivation and Duration In Virtual Reality

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Abstract—**Virtual reality (VR) exergames have become part of increasingly popular serious games because of both the fast development of VR technology and diversified dissemination of exergames. In this paper, we designed a built-in algorithm which based on the fatigue parameter to timely adjust the exergame's difficulty, especially in body-building/fitness exercise. The calculation method of fatigue index is obtained by using analytic hierarchy process (AHP) with six influencing factors: (1) average Heart Rate (avgHR); (2) Borg CR 6-20; (3) Calorie(s); (4) Accuracy Rate (Acc%); (5) Intensity; (6) Exercise time. Result from the experiments with 8 participants shows that the fitness exergame sorted by the auto-hierarchical algorithm we designed will be more effective than the traditional process by partly increasing both users' motivation and duration of playing exergame in the current phase.**

Keywords-computer-human interaction; data modeling; exergame; virtual reality

I. Introduction

Bodybuilding exergame is an inevitable action with the fantastic development of people's material life. Therefore, exergames rapidly occupy a big part of the serious-game market. However, fitness is far from a body-shaped result which via continuous exercise can reasonably and healthily achieve [1], but a privately customized program hinge on varying basic physical functions per se. However, motivating people to do exercise at an acceptable level of intensity and duration remains a challenge.

Benefits from both the widespread popularity of motion sensors and controllers (e.g., Kinect [2] and Wii Remote [3]) and unprecedented flourishing VR market which is based on the breakthrough of VR technology [4], people are no longer confined to using screen and mouse to play PC games to relieve pressure but choose more novel VR games to release their whole bodies [5]. These fitness-oriented games under virtual environment are called VR exergames [6], [7]. For instance, Xie et al. [8] have implemented an immersive full-body standing VR exergame and Xu et al. [9] have proposed a stepping-based dance exergame for both virtual reality and augmented reality environments.

However, both of their work focused on the discerning ability about body's movements in VR exergames instead of increasing participants' motivation. Ajoy et al. [10] show that not enough motivation made participants would experience a certain degree of fatigue after a period of time, and it also leaded to the less duration during experiencing VR exergames, which cannot reflect the significance of consumption in fitness. Inspired by their previous related work, we designed a build-in auto-hierarchical algorithm in a gesture-based seated VR exergame to increase users' motivation and duration. Figure 1 depicts the set-up experiment environment and devices which are implemented in our VR exergame.

The whole experiment is divided into three parts: (1) Pre-Experiment; (2) Traditional Exergame; (3) Auto-Hierarchy Exergame, and the result from the experiments with 8 participants shows that exergame sorted by the auto-hierarchical algorithm will be more effective than the traditional process in the current phase.

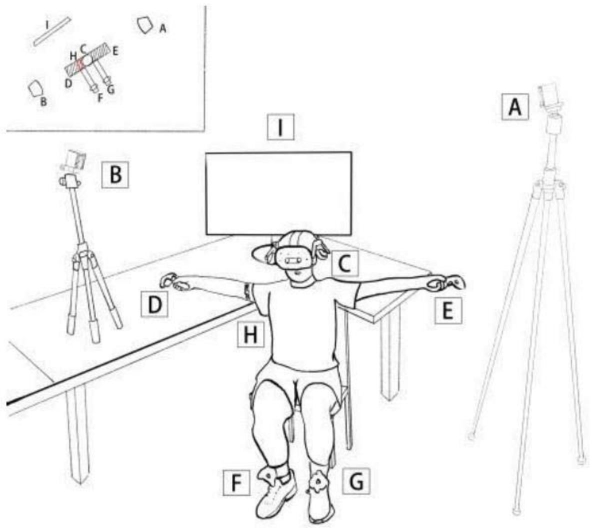

Figure 1. The set-up environment of experiments, and devices used in the experiment: (A&B) the VIVE base stations, (C) HTC VIVE Pro Eye, (D&E) the VIVE controllers used to track the player's hand positions, (F&G) the two VIVE trackers attached to the legs, (H) Polar OH1, (I) Computer Display Screen; the relative position can be seen in the top left-hand view.

II. Experiments and Users Study

A. Related Work

In this section, we provide our literature review to both standing and seated exergames and immersive exergames in virtual reality (VR) environment.

1) *Standing Exergames & Seated Exergames*

According to the players' body posture when running the exergame, we generally divide the exergames into two types: standing exergames and seated exergames. Previous motion-based standing exergames have always been focused on translating the traditional exercises into exergames. For example, in 2003, Tan Chua et al. started to implement Tai-Chi into virtual reality [11]. However, for the seated exergames, the previous related explorations are relatively limited. Unlike the standing exergames, seated exergames have been developed with a stationary exercycle. Thus, most players do not reach the minimum amount of recommended exercise. Christos et al. have developed VR exergames that support people of various abilities in getting the exercise they need, in an effective and motivating way [12, 13, 14, 15]. For instance, players will control a virtual cycle and perform cycling motion to focus on a higher heart rate to gain the best rewards or feedbacks.

Standing exergame can make the player have more immersive with objects in the virtual world, which could make the player hit other things accidentally easier in the room or be easily entangled by the USB-cable of VR Head-Mounted Displays (HMDs). Compared to standing exergame, players can be well protected in seated exergame. However, seated exergame could limit the player's movement and reduce motivation of exergames. Therefore, in order to strengthen the immersion of seated exergames, players can reasonably allocate their time under exergame levels, and automatically searching for the most appropriate gesture based on players' real-time fatigue index.

2) Immersive Exergames

Due to the highly development of virtual reality in this decade, this technology has been implemented into several scenes of life. Studies have shown that VR has the potential to produce benefits that other displays cannot offer (i.e., common TV or monitor). For instance, by modifying the avatar performance, VR exergames can give players the illusion of more exceptional physical capabilities than they have.

Our review of the literature shows several investigations of exergames in VR that ask players to play in a standing pose. Contrary to standing exergames, seated exergames have received little attention in VR. In this paper, we propose a gesture-based seated exergame in VR environment and design an auto-hierarchical data algorithm as a way of increasing the player's motivation and duration.

B. Pre-Experiment

1) Intensity

Considering that different participants have different basic physical qualities, we first measured each participants' intensities for six gestures (see Figure 2.) based on research from exercise science.

The game was implemented in Unity3D with the SteamVR plugin to enable the positional tracking of the HTC VIVE trackers and controllers.

The corresponded intensity for each exercise can be converted based on participants' heart rate (HR) calculated by the Karvonen formula [16].

$$I_{a\sim f} = \frac{avg\ \mathrm{HR} - rest\ \mathrm{HR}}{\max\ \mathrm{HR} - rest}$$

Where $I_{a\sim f} \in [0,1]$; max HR $= 220 - age$; *avg* HR is the average HR measured during each exercise; *rest* HR is the rest heart rate of the participant.

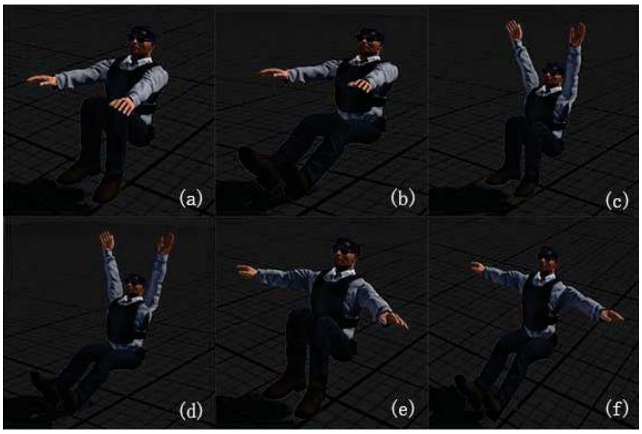

Figure 2. VR Exergame's Gestures: (a) hands lift and knees up; (b) hands lift and feet up; (c) hands up and knees up; (d) hands up and feet up; (e) hands stretch and knees up; (f) hands stretch and feet up.

2) Fatigue index

The auto-hierarchical algorithm is based on the fatigue index δ, and the calculation method of fatigue index δ is obtained via using analytic hierarchy process (AHP) [17] with six influencing factors: (1) average Heart Rate (*avg*HR); (2) Borg CR 6-20; (3) Calorie(s); (4) Accuracy Rate (Acc%); (5) Intensity;(6) Exercise time. After confirming the result have passed the consistency test, we got a pairwise comparison matrix based on the reflection of each participant' preference orientation. We also got the weight ratio (see Table 1.) of participants to the six factors via AHP calculation:

TABLE 1. AHP WEIGHT RATIO

Factors	Weight Ratio
avg HR	0.0866
Borg CR 6-20	0.3533
Calorie(s)	0.2704
Accuracy Rate	0.1148
Intensity	0.0505
Exercise time	0.1244

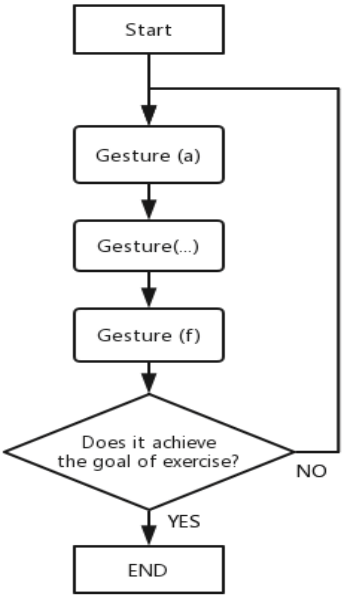

Figure 3. Traditional Exergame

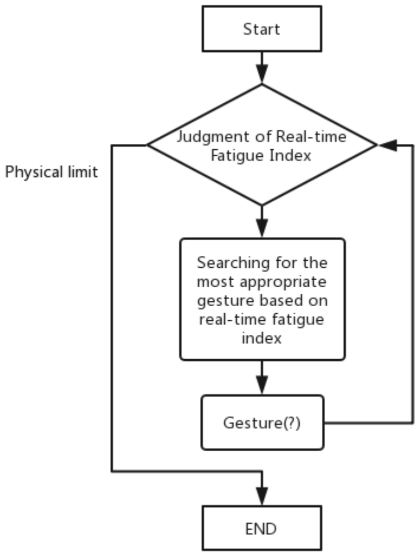

Figure 4. Auto-Hierarchical Exergame

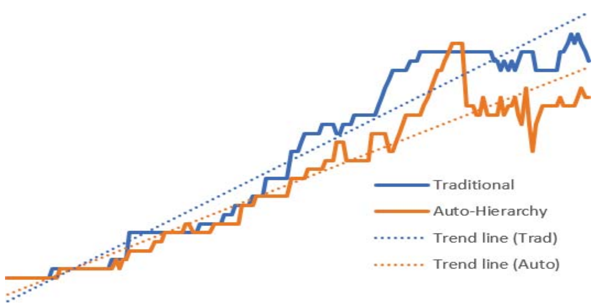

Figure 5. Real-time Fatigue Index δ - Duration Diagram

C. Contrast Experiment

We still used the same six-gesture exergame (see Figure 2.) to achieve the contrast experiment.

A diversion level of our diversion comprises of a grouping of work out motions. As the amusement began, the player was inquired to take after the signals of the demonstrate to move his/her body appropriately. Diverse signals required diverse levels of endeavors by players. For ease of playing, a motion was regarded completed on the off chance that particular joint (e.g., controllers, trackers) position of the player met the pre-defined factors of the comparing signals based on a basic rule-based framework and kept the posture for 0.3 seconds. To spur the player to take after the motions closely, both visual and sound feedbacks were given to empower the player to proceed playing.

We collected a few sorts of information within the back-end, counting (1) the activity completion time of each effectively performed motion, which was rise to the time went through by the client to perform the same posture and hold the posture for 0.3 seconds, (2) the Acc% for each motion sort, (3) the real-time HR information and Calories from the Polar OH1 optical heart rate sensor in each 0.2 moment, (4) the Borg CR 6-20 index.

Two different simple explanations of traditional exergame and auto-hierarchical exergame are provided (see Figure 3. and Figure 4.). We collected real-time heartbeats in the background (more precisely, every 0.2 seconds) in order to calculate the average heart rate of the subjects. At the same time, we recorded the subjects' resting heart rate before each experiment and ensured that this heart rate was within the normal range. After calculation based on these data, we got the value of "Real-time Fatigue Index δ-Duration" and plotted a comparison chart (see Figure 5.).

It must be mentioned that participants showed significant fatigue and breathing, and their average Borg Scale was as high as 16 at the end of the traditional exergame program. In another experiment (the auto-hierarchy experiment) that consumed almost the same calories (40±5 kcal), the average Borg Scale was much lower than 16 (the average was 12). In subsequent questioning, the participants in auto-hierarchy experiment indicated that they could continue to exercise for 20 to 30 minutes, even though they have consumed not less calories than traditional fitness. This also corresponds to the trend line in the Figure 5.

III. FUTURE WORK & CONCLUSION

Although our research has made great breakthroughs in theory, it can greatly improve people's duration in VR fitness exercise and achieve the effect of maintaining continuous physical exercise. A large-scale pre-test that contains assorted socioeconomics may be required for extending our approach to the common populace. Moreover, to play down players' cognition workload, we as it were utilized 6 gesture sorts that we measured amid the pilot study for situated exergames. Within the future, we might include other motions to extend the complexity of the amusement (i.e., more seated gestures, standing gestures). In addition, future work might utilize more parts and features to the virtual character. It is conceivable to utilize for occurrence sound to extend their level of inundation and make the amusement more alluring.

In this paper, we have presented an algorithm to automatically adjust the difficulty of a seated exergame and maintain a fairly stable calorie consumption at the same time. Result from the tests with 8 participants appears that the wellness exergame sorted by the auto-hierarchical calculation we outlined will be more viable than the conventional prepare by expanding both users' motivation and duration of playing exergame within the current stage.

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