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VCoach: Enabling Personalized Boxing Training in Virtual Reality

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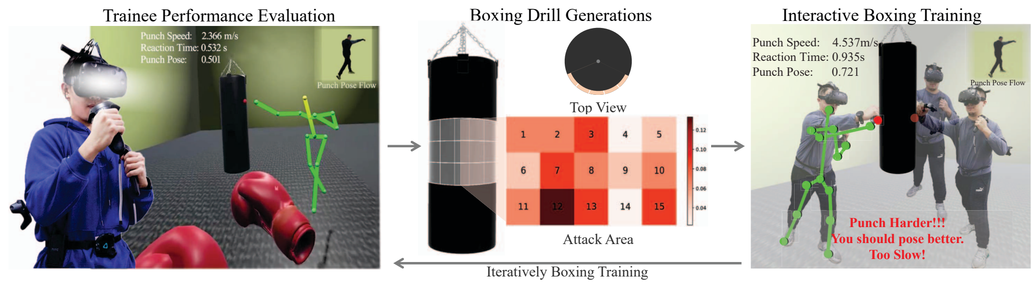

Figure 1: Overview of our virtual personalized boxing training system, VCoach, consisting of *Trainee Performance Evaluation*, *Boxing Drill Generation*, and *Interactive Boxing Training*. The trainee could experience the virtual boxing training to improve his skills iteratively through the consumer-grade wearable VR devices, *i.e.* HTC VIVE.

Abstract

We propose a training system in virtual reality, VCoach, automatically generating interactive and personalized boxing training drills for individual trainees. The training drill is generated in real-time based on the trainee's updated performance observed through wearable VR devices, including punch speed, reaction time, and punch pose. The training drill is visualized as a sequence of target points on a virtual heavy bag and the corresponding punch motion, as well as the performance feedback. Our experiments show that VCoach can generate personalized training drills to help trainees improve skills efficiently.

Index Terms: Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

Plenty of competitive sports have appeared in individual exercise, aiming to train one's strength, dynamic visual acuity, and reaction speed. One-on-one combat sport is a good example, which is widely used as an at-home workout for personal training, *e.g.*, boxing with different powerful single punches. Due to the features of high-speed and complex actions, continuous specific guidance is needed for such exercise, keeping the exercise process efficient and safe [1, 5]. However, the professional guidance and training are costly.

The growing popularity of consumer-grade VR devices offers new opportunities for immersive sports training, *e.g.*, providing virtual instructions and training for Tai Chi [2], table tennis [8], basketball [4], skiing [3, 7], and slope-related motions [7]. Moreover, Lopez *et al*. [6] used electric muscle to simulate haptic impact sensation in boxing. Inspired by these studies, we propose a virtual boxing training system, VCoach, aiming to generate personalized boxing drills adaptively based on trainees' real-time training performance.

2 System Framework

Our goal is to help trainees to improve boxing skills according to their current boxing performance. Considering the performance varies during the excising, we design a system, VCoach, with generated personalized training drills, akin to the training flow in the boxing club, *i.e.* evaluating, tailoring training plans, and exercising.

Fig. 1 shows the framework of VCoach. i) With the wearable VR device, the trainee performs the boxing training. Simultaneously, VCoach captures the punch speed, reaction time, and punch pose. ii) VCoach computes the trainee's boxing performance in each attack area (15 cells on the heavy bag from the trainee's view, represented as $A = \{a_1, ..., a_{15}\}$), and generates a personalized boxing drill (a sequence of target points in A) based on the trainee's exposed weakness. iii) During the training, VCoach provides detailed guidance, including stand position, punch pose flow, and real-time performance ratings. The training process performs iteratively, *i.e.* VCoach could adjust the drills with the changing of the trainee's performances.

Trainee Performance Evaluation. VCoach analyzes the trainees' boxing performance by measuring the difference between trainees' locomotion parameters (punch speed, reaction time, punch pose) and pre-collected professional boxing coach's one for guiding the boxing drill generation. To be specific, punch speed is the instantaneous speed when the trainee's boxing glove collides with the target point. Reaction time is calculated as the interval from the target appearing to the target being punched. And punch pose is defined as the posture the trainee hits the target with.

For the ith area, the professional coach results at each point were recorded as s_{c,a_i} (punch speed), t_{c,a_i} (reaction time), and p_{c,a_i} (punch pose). Similarly, the trainee's results were recorded as s_{t,a_i}, t_{t,a_i} and p_{t,a_i}. For each target point a_i, the trainee's punch speed performance $E_s(a_i)$ and reaction time performance $E_t(a_i)$ are defined as:

$$E_s(a_i) = \frac{\max(s_{c,a_i} - s_{t,a_i}, 0)}{\sum_{i=1}^{15} \max(s_{c,a_i} - s_{t,a_i}, 0)}, E_t(a_i) = \frac{\max(t_{t,a_i} - t_{c,a_i}, 0)}{\sum_{i=1}^{15} \max(t_{t,a_i} - t_{c,a_i}, 0)}.$$

With the wearable VR devices (HTC VIVE), *i.e.* one head-mounted device, two handheld controllers, and three wearable trackers fixed at elbows and waist, VCoach could track the trainee's pose in real-time. As shown in Fig. 2, the punch pose is represented by six 3-dimensional normalized vectors, showing the direction of each two keypoints in the 3D environment. We train a three-layer fully connected neural network for the pose performance clas-

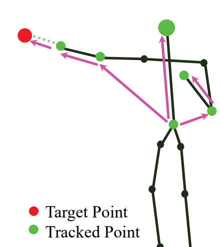

Figure 2: Pose representation.

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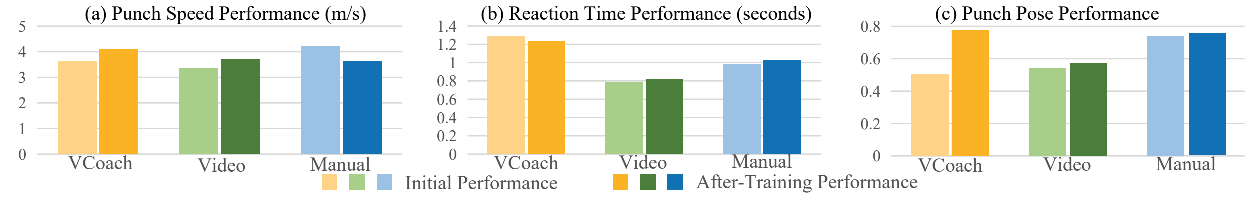

Figure 3: The results of boxing performance evaluations in our experiments, including the *Initial Performance* and *After-Training Performance* across different training approaches in terms of punch speed, reaction time, and punch pose, respectively. Note that, the higher the performance evaluations of punch speed and punch pose the better, while that of the reaction time is the opposite.

sification. We labeled the boxing punch pose of a professional boxer as positive examples, *i.e*. the pose when the boxer hit the target point. Five amateurs were recruited to collect negative examples. After training, the model achieves accuracies of 99.23% for the jab, 99.45% for cross, and 96.45% for the hook. Therefore, the performance of the punch pose can be defined as $E_p(a_i) = 1 - p \cdot cos(|\theta_{t,a_i} - \theta_{c,a_i}|)$, where p is the sigmoid output of our classifier stating the possibility that the pose is good. We further record the boxer's moving angles horizontally relative to the heave bag center when punching target points. The moving angle of the trainee and the coach, *i.e*. θ_{t,a_i} and θ_{c,a_i}), should be as close as possible.

Boxing Drill Generation. Let $L = (l_1, l_2, \dots, l_N)$ denotes the generated boxing drill, which consists of N target points in one drill (N a is customizable length, set as 45 in default), covering different attack areas, *i.e*. $l_i \in A$. From the evaluation phase, a distribution of the trainee performance on each designed metric is obtained, reflecting which target point the trainee needs to improve at. Formally, at the i-th target point, the total performance is written as:

$$C_{total}(a_i) = \omega_1 E_s(a_i) + \omega_2 E_t(a_i) + \omega_3 E_p(a_i), \tag{1}$$

ω_1, ω_2 and ω_3 are regularization factors to balance these three terms. By default, they are set to $(\omega_1, \omega_2, \omega_3) = (0.6, 0.3, 0.1)$ according to the professional boxer's advice for beginners. Then the total performance is normalized by $\sum_{i=1}^{15} C_{total}(a_i)$ to form the performance distribution $\mathscr{D}$. Finally, VCoach assigns a training frequency for each target point, which follows the distribution of $1 - \mathscr{D}$ for real-time adaptive generation.

Interactive Boxing Training. After generating a boxing drill, VCoach visualizes the target point one by one. As shown in Fig. 1, VCoach provides three kinds of guidance for trainees to improve their boxing skills, which are intuitive and easy to understand: (1) diverse feedback, including parameterized punch performance and vivid comments; (2) trainee-adapted 3D skeleton, showing standard punch pose in the appropriate standing position for each punch target; (3) professional punch pose flow, demonstrating the professional motion flow of the corresponding punch type.

3 Experiment

We implemented our VCoach using C# and Unity 2019 and ran on a PC equipped with 16GB of RAM, an Nvidia 1080Ti graphics card with 12GB of memory, and a 2.60GHz Intel i7-5820K processor. To validate the outstanding effectiveness of VCoach among popular online boxing training methods, we recruited 15 boxing beginners (9 male and 6 female) whose ages ranged from 19 to 23 ($M = 22.13, SD = 1.12$). Take the cross punch boxing training as an example, we conducted perceptual studies accordingly.

The 15 participants were randomly divided into 3 groups, receiving three different training approaches for 15 minutes respectively: (1) *VCoach*, training with our virtual boxing coach; (2) *Video*, training by watching two relevant top-rated YouTube videos; (3) *Manual*, training by reading Team USA Boxing training manual. We collected each participant's initial and after-Training Performance by asking them to perform boxing with a pre-generated drill, including 15 targets uniform distributed in 15 attack areas. Note that we used the similar evaluation methods illustrated above but only collected the directly obtained values, not the one compared with the coach.

In order to reduce the impact of individual differences for the evaluations, as shown in Fig. 3, we pay more attention to the differences between the boxing performance evaluations obtained before and after different training approaches.

With the training guidance of VCoach, participants' punch speed averagely increased 0.468 m/s, followed that of the training with videos (0.384 m/s), while manual training group decreased 0.57 m/s. For the reaction time, the *VCoach* group perform better (decreased 6 ms) than that of the other groups (*i.e*. increased 38.5 ms for *video* group and increased 37.9 ms for *manual* group). The decreased reaction time of the VCoach group can attribute to the guidance visualizations during the training process. For the punch pose, there is a stark contrast between the evaluated punch pose between *VCoach* and the other two groups, *i.e*. the average pose rating significantly increased 0.272 for *VCoach*, while the results of other group did not change obviously. We believe that the immersive training experience in *VCoach* may account for its higher effectiveness compared to the training approaches based on videos or manual, which may suffer from a gap between theory and practice.

4 Conclusion

In this paper, we introduce VCoach, a personalized virtual reality-based approach to help amateurs with their boxing skills. Through modeling the performance for each individual trainee, the generated training drill by VCoach will be more targeted. Compared to traditional training approaches, our approach has the advantages of lower cost. Furthermore, the visualized vivid guidance is more efficient and adaptable. Through the user study, we validate that the participants may feel more motivated to receive training by VCoach compared to that of reading handbooks or watching videos. The core idea of VCoach could also be extended to other online sports for providing efficient and scientific online training experience.

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