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Posture-based and action-based graphs for boxing skill visualization

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ABSTRACT

Automatic evaluation of sports skills has been an active research area. However, most of the existing research focuses on low-level features such as movement speed and strength. In this work, we propose a framework for automatic motion analysis and visualization, which allows us to evaluate high-level skills such as the richness of actions, the flexibility of transitions and the unpredictability of action patterns. The core of our framework is the construction and visualization of the posture-based graph that focuses on the standard postures for launching and ending actions, as well as the action-based graph that focuses on the preference of actions and their transition probability. We further propose two numerical indices, the Connectivity Index and the Action Strategy Index, to assess skill level according to the graph. We demonstrate our framework with motions captured from different boxers. Experimental results demonstrate that our system can effectively visualize the strengths and weaknesses of the boxers.

1. Introduction

Computer technologies have taken on a crucial role in modern sports and health sciences, in revolutionizing the way to observe, analyze, and improve the performance of both amateur and professional athletes. Computer-managed weight lifting machines, treadmills and many other training equipment provide energy consumption or repetition and weight management in many sport clubs. Virtual reality technology has been applied in various training systems in baseball [1], handball [2] and tennis [3] to assist more professional sport activities. Nevertheless, these technologies are only able to analyze motions at a low level, i.e. recording the timing or repetitions of basic motions and comparing movement trajectories with those performed by better players. More advanced technologies are needed for personalized and higher-level analysis comparable to that from human experts.

In addition to the instantaneous movement features of the sports players, Experienced sport coaches consider high-level features such as the variety of actions and quality of transitions from one action to another. Taking boxing as an example, professional boxers have in basic actions such as defence, stepping and attack, threading through which the transitions are carried out based on the strategy and the opponent's reactions. The action transitions of a good boxer need to be flexible and contain great variety to achieve the optimal outcome. Such information often serves as an important indicator in assessing the skill level of a player, and the same principle applies to many other sports such as basketball [4] and fencing [5]. Unfortunately, automatic systems for analyzing and evaluating sports motions at such a high level is very limited.

In this paper, we propose a robust visualization system to address the above limitations, by represent motions as an interactive graph of high-level features, including the flexibility and richness of the actions as well as the transitions of actions. Although we use boxing as a demonstration in this paper, our method is generic and can be applied to different sports. Our approach starts with capturing the *shadow boxing* training motion of a boxer, in which the boxer performs boxing with an imaginary opponent. An experienced coach can effectively assess the boxer's skill by watching the shadowing boxing motions. As a positive side effect, this method of motion analysis greatly reduces the complexity of motion capture due to occlusion and collision and has shown to be very effective in our system. The motion data is then processed and visualized in two different graphs: the posture-based graph and the action-based graph, for performance analysis.

In the posture-based graph, the semantic actions segmented from the captured motion are grouped into clusters based on a customized distance function that considers action specific features. Our system then automatically generates a motion graph structure known as *Fat Graph* [6], which uses nodes to represent

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groups of similar postures to start and end actions, and edges to represent groups of action. By applying dimensional reduction techniques, this graph can be visualized in a 3D space for performance analysis and evaluation. The transition capability of the boxer are visualized by the connectivity of the nodes, where the richness and preference of the actions are visualized by the edges in the graph. We further propose a skill evaluation metric known as the *Connectivity Index* which evaluates the richness of actions and the flexibility of transitions according to the graph.

Whilst the posture-based graph focuses on the variety of basic postures and the transition flexibility between actions, the action-based graph mainly considers the richness of actions and the transition probability among them. The action-based graph is constructed as a customized Hidden Markov Model (HMM) [7], in which similar actions are grouped into clusters that formulate the nodes. The transition probability among actions is calculated and is expressed as edges between nodes. The graph is visualized in a 3D space, and the positions of the nodes and edges are optimized for better visualization. With such a graph, the pattern of action launching can be easily identified in order to assess the boxing strategy of the boxer. We further propose the *Action Strategy Index* to evaluate the unpredictability of action patterns according to the graph.

We conducted experiments on the motions captured from multiple boxers and evaluate their skills. The corresponding posture-based and action-based graphs were generated. As shown in Fig. 10, we can easily evaluate the skills of different boxers with our visualization system.

There are three main contributions of this work:

- We propose a framework for high-level skill analysis through automatic motion analysis and visualization. Given a captured motion from a sports player, our system automatically segments the motion into semantic action units and constructs two graph structures.
- We propose the posture-based graph, which is a variant of the Fat Graph, to visualize the skills according to different standard postures for launching and ending actions. It allows the user to identify the correctness of standard postures and the diversity of actions. We further propose the Connectivity Index that evaluates the richness of actions and the flexibility of transitions.
- We propose the action-based graph, which is a variant of the Hidden Markov Model (HMM), to visualize the skill according to different groups of action. It allows the user to identify the preference of actions and their transition probability. We further propose the Action Strategy Index to evaluate the unpredictability of action patterns.

The preliminary results of this work were published in a conference paper [8], which proposed only the posture-based graph. In this paper, we extend the work by introducing the new action-based graph. We perform analysis and experimental evaluation of such a graph, and compare its performance with the posture-based graph. We have also updated the paper thoroughly such that the two graphs are presented in an organized and effective manner.

The rest of this paper is organized as follows. Related works are reviewed in Section 2. The details of motion capture and organization are given in Section 3. In Sections 4 and 5, we explain the design and implementation of the posture-based graph and the action-based graph respectively. Related experiments can be found in Section 6. The paper is concluded in Section 7 with future research directions discussed.

2. Related work

2.1. Sports visualization

Helping athletes on skill improving via the visualization of sport motions is a field that has not been fully explored in the field of sports science. Existing research [9,10] mainly focuses on the appearance changes of motions when body and motion parameters are changed. For example, Yeadon [9,10] has done research on how diving and somersault motions change when the motions are launched at different timings by using physical simulation. Although such tools are useful for the athletes to interactively visualize possible results under different parameters, they can only evaluate the performance of sports that do not require complex maneuvers and strategies, such as jumping, high jumping, sky jumping, or somersaults. In many sports games, the performance depends not only on physical factors such as velocity, power and strength, but also on flexibility to switch from one motion to another and richness of the player's motions. This high-level information has not been used to visualize the skills of the athlete in previous research and it is the major difference between our work and the afore-mentioned ones. In this research, we combine the approaches of motion graph [11–13] and dimensionality reduction [14,15] to visualize high-level skills information of the athletes for the skill assessments.

2.2. Motion graphs for motion modeling

The Motion Graph approach [11–13,16–19] is a method to interactively reproduce continuous motions based on a graph generated from captured motion data. Reitsma and Pollard [20] compared different motion graph techniques comprehensively. Heck et al. [21] further parametrized the motion space to control how the motions are generated by blending samples in the motion graph. Such an approach can be used for interactive character control such as that in computer games. When it comes to graph construction, [16,17] are the ones most similar to our method. Min et al. [16] grouped similar postures and transitions into nodes and edges. Their focus was the motion variety of synthesized motions so they used generative models to fit the posture and motion data. Our focus is on skill visualization through the analysis of postures and motions so we can afford simpler and faster methods of analysis. Beaudoin et al. [17] cluster postures first then find motion motifs by converting the motion matching task into a string matching problem. Their priority was to find motifs that were representative while our focus is to visualize motion details and statistics to help people assess the skills. Xia et al.[22] constructed a series of local mixtures of autoregressive models (MAR) for modeling the style variations among different motions for real-time style transfer. They demonstrated style-rich motions can be generated by combining their method and motion graph.

Since the Motion Graph produces a lot of edges and nodes without any context, it becomes difficult to control generated motion as the user wishes. Safonova and Hodgins [23] optimized the graph structure by combining motion graph and interpolation techniques to improve performance. On the other hand, works to resolve this problem by introducing a hierarchical structure were proposed [6]. These approaches add topological structures into the continuous unstructured data so that the motion synthesis can be done at a higher level. In a sport like boxing, it is possible to create a motion graph of semantic actions such as attack and defence, which is known as the action-level motion graph [24,25]. A recent work by Hyun et al. [4] proposed *Motion Grammars* to specify how character animations are generated by high-level symbolic description. Such an approach can be used with existing animation systems which are built based on motion graphs. Ho and Komura

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