Towards Real-Time Multi-Sensor Golf Swing Classification Using Deep CNNs

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ABSTRACT

In recent years, smart sports equipment and body sensor systems have become popular in professional and amateur sports. One of a few remaining problems in real-time applications is the discovery of knowledge from the embedded sensors data. In sports training, such knowledge helps accelerated motor learning. The authors start with exploring the possibilities of the classification of golf swing performance with the 1-D convolutional neural network (CNN) in real-time. They thoroughly investigate multiple golf swing data classifiers based on CNNs fed with multi-sensor signals. The authors test the possibilities of real-time performance of CNN methods on the multi-length sequences. In addition, they thoroughly evaluate the performance of their well-trained CNN-based classifier on the aforementioned test set in terms of common indicators. Experiments and corresponding results show that the authors’ models can satisfy the real-time requirement of the accuracy of the classification and outperform support vector machine (SVM).

KEYWORDS

Biofeedback System, Convolutional Neural Network, Golf Swing Classification, Real-Time Golf Classification, Sensor Signals, Smart Sport Equipment

1. INTRODUCTION

Data science and technology play more significant roles in professional sports, amateur sports, and recreational sports, than ever before. After collecting the sport performance data with the integration of sensors, sensor networks, and communication technologies, the discovery of knowledge of interest in these data is necessary. Consequently, novel data mining technologies should be employed. Data volume and time constraints are both demanding aspects of such analysis.

From the sensors attached to bodies of users and/or embedded into the smart equipment, instructors are capable to oversee the complete actions in a group sports match and even go into details of popular movements. In practice, using data from customized biofeedback applications, particularly biomechanical feedback systems with terminal and/or concurrent feedback (Umek, Tomažič, & Kos,

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2015) is insightful; a system for proper motor learning, for example, can be effectively implemented by identifying and preventing incorrect actions (Sigrist, Rauter, Riener, & Wolf, 2013). Furthermore, if a biofeedback system identifies specific actions in real time, users can be notified about detected errors and prompted to abort incorrect actions; consequently, motor learning is accelerated and more efficient. One of the major obstacles is not only the discovery of the incorrect actions from the sensor data, but the discovery of such actions in real time - during the execution of the action. Real time operation of biofeedback systems that give concurrent feedback to the user is our ultimate goal and motivation. For the purpose, we aim to devise a real-time application capable of notifying users about their improper movements.

Convolutional neural network (CNN) has been one of the most efficient classification approaches in the field of computer vision including image classification, object recognition, image retrieval, and image generation (Guo et al., 2016; Goodfellow et al., 2014; Arjovsky, Chintala, & Bottou, 2017; Radford, Metz, & Chintala, 2015; Pathak, Krahenbuhl, Donahue, Darrell, & Efros, 2016; Yang et al., 2016). Some CNN incarnations including AlexNet (Krizhevsky, Sutskever, & Hinton, 2012), VGGNet (Simonyan & Zisserman, 2014), GoogLeNet (Szegedy et al., 2015), and ResNet (He, Zhang, Ren, & Sun, 2016) have achieved superb accuracy compared with traditional classification approaches. Inspired by features of CNN-based models, such as its automatic feature extraction and high accuracy, we design CNN-based classifiers for the classification of our real-world golf swing signals in the real-time application setting. Dataset is collected by our customized golf club integrating two orthogonally affixed strain gage sensors, 3-axis accelerometer, and 3-axis gyroscope (Umek et al., 2015). We first assemble the multi-class real-world golf swing dataset from a number of professional and amateur golf players. Then we test the real-time performance of CNN methods on the multi-length golf swings by pruning golf swing sequences to simulate the real-time application setting. Next, we thoroughly evaluate the performance of our well-trained CNN-based classifier on the aforementioned test set in terms of common indicators including accuracy, precision-recall, and F1-score. Experimental results show that our CNN-based models can satisfy the requirement of the accuracy of golf swing classification, and outperform support vector machine (SVM) method in terms of quantitatively exceeding these indicators.

The contributions of our paper are presented here:

- We present well-customized golf swing classification models based on convolutional neural networks and fully employ them to identify 1-D golf swing sequences;
- We thoroughly test and compare the real-time performance of CNN-based classification models by pruning golf swing sequences; we further quantitatively compare the real-time performance between CNN-based models and SVM on behalf of traditional methods in terms of conventional indicators;
- We also thoroughly explore the real-time performance of CNN-based models and SVM with respect to multiple sensors and multiple models, and we confirm that CNN-based models outperform the SVM model.

The paper is organized as follows: Section 2 summarizes related work regarding classification methods based on CNN. Section 3 introduces our network architecture. Section 4 presents the experiments and results for the validation of the effectiveness of our models. Section 5 presents comparisons and conclusions. Section 6 concludes the paper and introduces future plans.

2. RELATED WORK

Machine learning techniques have been utilized to detect abnormal 1-D signals in which classification and clustering are common components in the identification. Ros, Mota, Fernández, Toro, and
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Preserving Relationship Cardinality Constraints in Relational Schemata
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