

Using CNN- VGG 16 to detect the tennis motion tracking by information entropy and unascertained measurement theory

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Abstract. Object detection has always been to pursue objects with particular properties or representations and to predict details on objects including the positions, sizes and angle of rotation in the current picture. This was a very important subject of computer vision science. While vision-based object tracking strategies for the analysis of competitive videos have been developed, it is still difficult to accurately identify and position a speedy small ball. In this study, deep learning (DP) network was developed to face these obstacles in the study of tennis motion tracking from a complex perspective to understand the performance of athletes. This research has used CNN-VGG 16 to tracking the tennis ball from broadcasting videos while their images are distorted, thin and often invisible not only to identify the image of the ball from a single frame, but also to learn patterns from consecutive frames, then VGG 16 takes images with 640 to 360 sizes to locate the ball and obtain high accuracy in public videos. VGG 16 tests 99.6%, 96.63%, and 99.5%, respectively, of accuracy. In order to avoid overfitting, 9 additional videos and a subset of the previous dataset are partly labelled for the 10-fold cross-validation. The results show that CNN-VGG 16 outperforms the standard approach by a wide margin and provides excellent ball tracking performance.

Keywords: computer vision science; deep learning (DP); information entropy; unascertained measurement theory

1. Introduction

Tracking and recognition of motion objects has been commonly used in numerous areas, including food safety tracking (Wu and Sun 2013), traffic movement tracking (Hashmi and Keskar 2012) and unauthorized tracking (Wei *et al.* 2012) in identification and monitoring of moving items by computer vision technologies. Region-based tracking (Zhao *et al.* 2007), contour-based tracking (Birchfield and Rangarajan 2005) and model-based tracking (Yilmaz *et al.* 2004) are the primary approaches used to detect moving objects. A number of studies (Babenko *et al.* 2009, Kalal *et al.* 2011, Bai and Tang 2012, Jia *et al.* 2012, Park *et al.* 2012, Zhang *et al.* 2013, He *et al.* 2015) have indicated representative object tracking algorithms in recent years (He *et al.* 2021, Huo *et al.* 2021, Shao *et al.* 2021). Considering the use of algorithms for object tracking for decades, there are still problems (Guo *et al.* 2021a, Hou *et al.* 2021, Huang *et al.* 2021c, Jiao *et al.* 2021). There are few parameters affecting the object tracking algorithms, such as illumination changes, occlusion and complex backgrounds. Whilst, to effectively address all the challenges caused by the factors mentioned, no robust algorithm has been evolved. In this study, tracking algorithms seeks to somehow find a solution to these problems. Object features is a crucial parameter for any tracking algorithm. In tracking, (Hager and Belhumeur

1998, Matthews *et al.* 2004, Alt *et al.* 2010) the general object template is widely used. Mei *et al.* (2011) used sparse images to find changes in the appearance of the object. Apart from the template, numerous features, such as color hystero grams (Jia *et al.* 2012), histograms of oriented gradients (HOG) (Dalal and Triggs 2005), region covariance descriptors (Porikli *et al.* 2006, Tuzel *et al.* 2006, Wu *et al.* 2012), hair-like features (Viola and Jones 2004, Grabner *et al.* 2006) and ORB (Rublee *et al.* 2011) were used in tracking of algorithms.

Moreover, a large number of particle filters are used in object-tracking algorithms (Pérez *et al.* 2002, Kalal *et al.* 2011) due to their high calculation performance. In this article, a new method was suggested on the basis of entropy of information and compressed sensing. The movement of an object is a continuing mechanism between the preceding frame and the next. The difference in object displacement between adjacent frames is important in a restricted range (Zhou *et al.* 2018, Ding *et al.* 2020, He *et al.* 2020, Wu *et al.* 2020, Zhao *et al.* 2020, Cao *et al.* 2021a, b, c, Jiang and Li 2021, Li *et al.* 2021, Liu *et al.* 2021a, d, Lv *et al.* 2021, Ma *et al.* 2021b, Wu *et al.* 2021, Zheng *et al.* 2021a, b). For example, in Fig. 4, the object region is defined by red rectangle. So, the object area naturally in the next frame does not exceed the border of the blue rectangle that is specified in (Zhang *et al.* 2014) as a local context. The particle coordinates must be put under a limit when forming particles. We move the particles to the restricted area for certain particles outside the local background. The scale of an object position tracking can be fairly adjusted according to the speed of motion of the object to some extent (Azimi *et al.* 2016, Ebrahimi and Shafiei 2016, Ghadiri *et al.*

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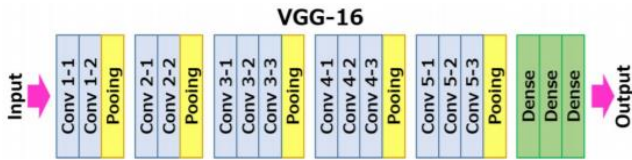


Fig. 1 VGG 16 structure

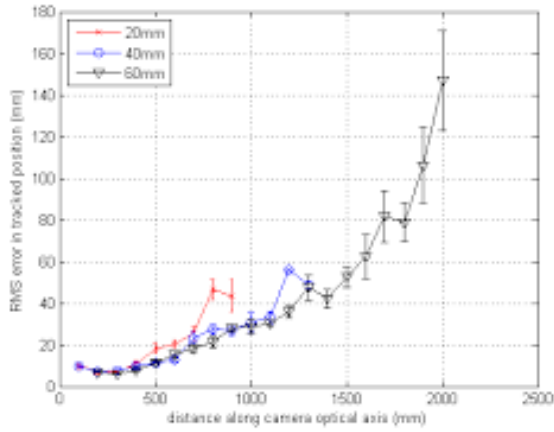


Fig. 2 Experiment 1. RMS position tracking error for a single marker with a planar angle of 0 degrees, Marker sizes $x - 2q = y - 2q$ 20 mm, 40 mm and 60 mm were tracked at distances of 100 mm through 2000 mm

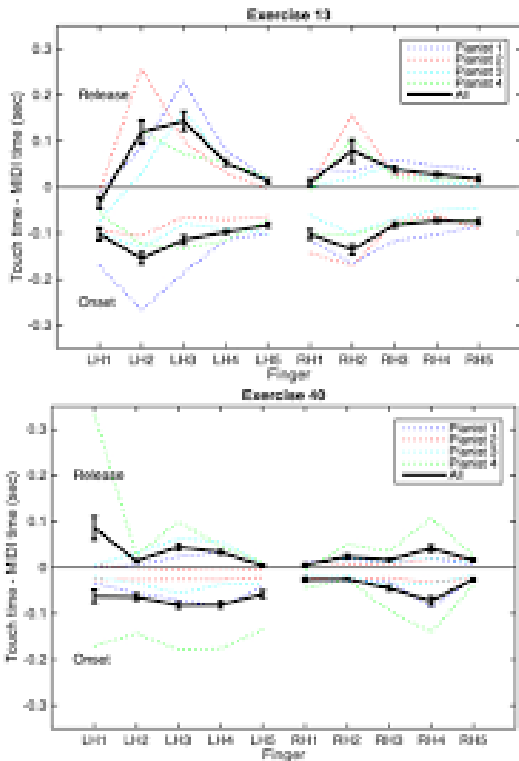


Fig. 3 Integrating optical finger motion tracking with surface touch events

2016a, b, c, d, Ghadiri and Shafiei 2016a, b, c, Shafiei *et al.* 2016a, b, c, d, e, f, g).

Ball tracking data is one of the significant and useful information for game analysis. Regarding the fast motion of ball, this makes the job of ball tracking more complex than

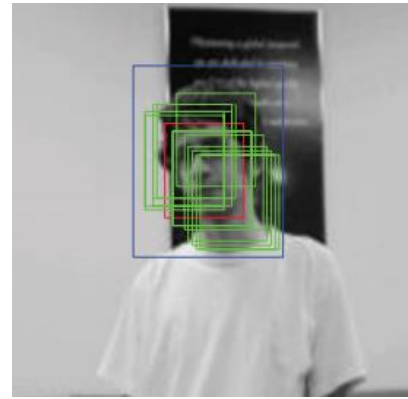


Fig. 4 The illustration local content

other sports (Guo *et al.* 2021b, He *et al.* 2021, Zhang *et al.* 2021a, c). Here, a deep learning network was built based on a heat map as CNN-VGG16 to track tennis balls precisely on broadcast videos or videos (Mansouri *et al.* 2016, Shariati *et al.* 2019c, e, Trung *et al.* 2019b, Yazdani *et al.* 2020). VGG16 find the issues of remnant and blurry images and could also spot occluded ball by learning its trajectory patterns (Arabnejad Khanouki *et al.* 2010a, Mojtaba 2011, Sinaei *et al.* 2012, Shariati *et al.* 2020h, Davoodnabi *et al.* 2021). Other ball-based competitions will be covered in the new network and amateur, as well as professional teams can gather data on a modest budget (Huang *et al.* 2021a, Liu *et al.* 2021c, Peng *et al.* 2021, Zhang *et al.* 2021b). Standard identification of images is typically determined by the presence of an object, such as structure, color, size, etc. Due to an arXiv:1907.03698v1 [cs.LG], long shutter time on prosumer or consumer cameras images of speedy objects are vulnerable to after image problems or blurred problems which result in low accuracy of recognition. VGG-16 (Simonyan and Zisserman 2014) is one of the most common map encoding networks. The R-CNN family (Girshick *et al.* 2014, Ren *et al.* 2015, Zhao *et al.* 2019) examines the image in two stages, in order to find and classify several objects in one image. It initially selects a large number of areas that might include interesting objects called Region of Interests (RoIs) and then detect and grade models for these regions. This study proposes a DP network (VGG16) to develop an exact tracking network (Shariati *et al.* 2011a, 2019d, Ziaei-Nia *et al.* 2018, Trung *et al.* 2019a, Afshar *et al.* 2020). To generate the function map, a VGG-16 is adopted. VGG16 can take several consecutive frames as data, unlike other profound learning networks. In this way, VGG16 not only studies the characteristics of the ball, but also the trajectory features to improve its ability to identify and position objects. The network follows FCN's sampling protocol in order to produce the heat map for object detection so images are sampled and encoded by grouping layers (Dai *et al.* 2021a, b, Liu *et al.* 2021b, Najaafi *et al.* 2021, Wu and Habibi 2021). Finally, it is determined by the heat map of a deep-learning network the place of our target object. To test the output of the consecutive technique of input frames, VGG16 are implemented in both single and multiple frames (Bai *et al.* 2020, Ghazanfari *et al.* 2020, Li *et al.* 2020b, Liu *et al.* 2020b, Wang *et al.* 2020, Ghabussi *et al.* 2021). A detailed

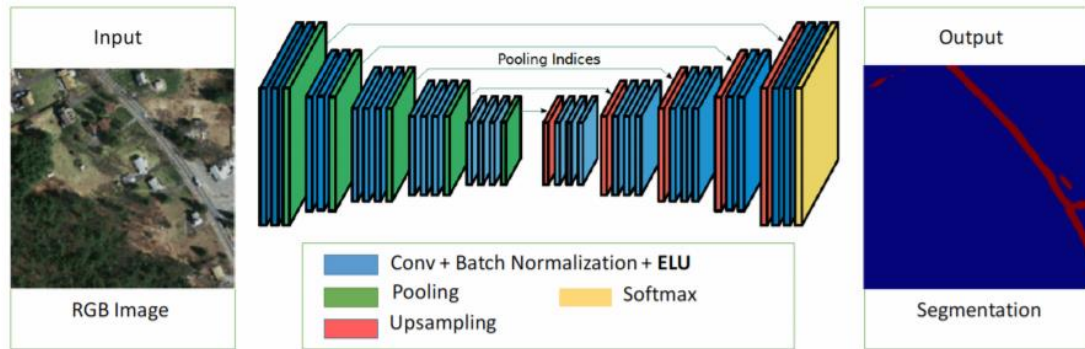


Fig. 5 Proposed network architecture for object segmentation

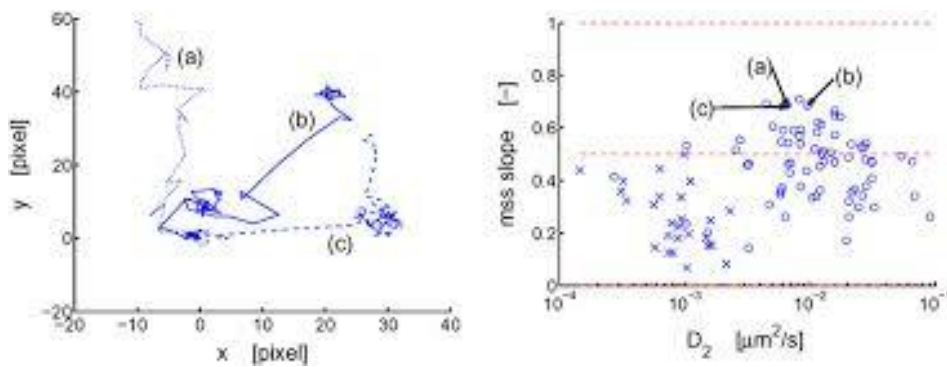


Fig. 6 Feature point tracking and trajectory analysis

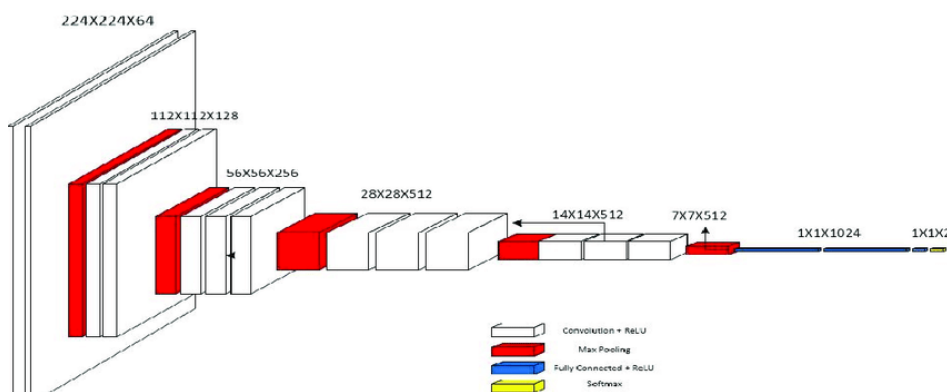


Fig. 7 CNN based on VGG16

analysis is conducted between various models, along with the traditional image-recognition model (Mohammadhassani *et al.* 2014, Archana and Geetha 2015, Shariati *et al.* 2019b, 2020d, f, 2021b). Experiments reveal that VGG16 proposed a higher performance than the traditional image recognition methods and efficiently determines the location of quick-moving tennis balls from sports videos of televised sport (Nosrati *et al.* 2018, Milovancevic *et al.* 2019, Sajedi and Shariati 2019, Alipour *et al.* 2020, Li *et al.* 2020a, Liu *et al.* 2020a). Additional data from the nine tennis games held at various courts, comprising red clay courtyard, grass court, hard court, etc. were applied to the testing of dataset to avoid the notorious overfitting issue often observed in DP solutions (Arabnejad Khanouki *et al.* 2010b, Abdolrahim 2012, Khorami *et al.* 2017a, b, Zandi *et al.* 2018, Shariati *et al.* 2020c). The video from 2018 Indonesia Open Final has

been classified 18, 242 frames. The tennis tracking application provides excellent efficiency at 10-fold cross validity, which includes 95.3% accuracy, 75.7% recall and 84.3% F1 measure. The ability to extend the scope of visually oriented programming programs shows tremendous potential (Ebrahimi and Shafiei 2017, Ebrahimi *et al.* 2017, Ehyaei *et al.* 2017, Ghadiri *et al.* 2017a, b, c, d, e, Mirjavadi *et al.* 2017a, b, c, d, Shafiei and Kazemi 2017a, b, Shafiei *et al.* 2017a, b, c, d, 2019, 2020, Azimi *et al.* 2018, Shafiei and She 2018).

These methods are eventually used for a large scale image recognition model VGG16, which is a CNN architecture developed by Simonyan and Zisserman. VGG16 is a neural network of 16 layers without counting the max pooling layer and the layer of Softmax. In this analysis, there is a 96% improvement in model train



Fig. 8 Revolutionizing tennis with machine learning

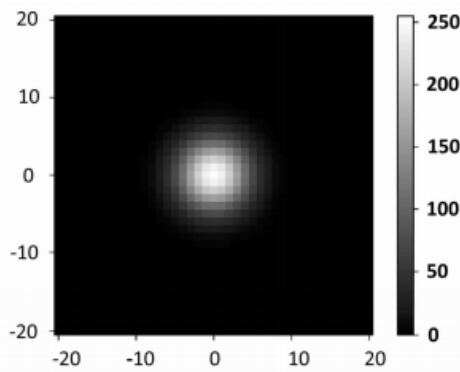


Fig. 9 Example of detection heatmap

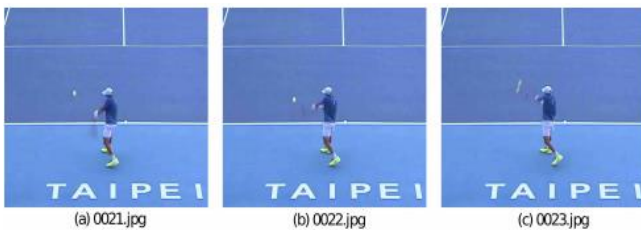


Fig. 10 A hit case (a) and (b) are labeled as flying, (c) hit

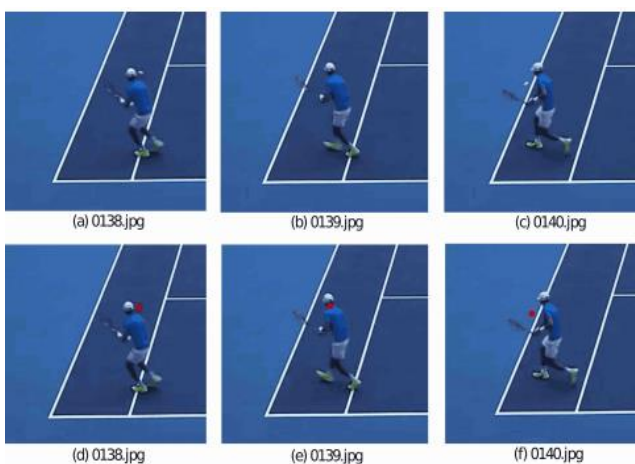


Fig. 11 The ball is occluded by the player

accuracy for the model VGG16 and 92% reliable test accuracy with train and test losses below 0.5. The average image classification error rate decreases to 8%, while the single -class error rate are less than 7.5% in eight out of ten

image classes. It was concluded that it was necessary to minimize the mode overfitting and a more accurate CNN model, hyper-parameter tuning and data improvement (Shariati *et al.* 2012a, b, 2013, 2014, 2017, Zhang *et al.* 2018). A suggested approach to merge entropy weight and expert preferential weigh is employed, the assessment indexes of black-start are fairly fuzzified, and schemes are sorted in line with relative superiors and inferiors by the use of fuzzy assessment data from schemas and through fuzzy comprehensive assessment (Lin *et al.* 2012, Khanouki *et al.* 2016, Shah *et al.* 2016a, b, Shariati *et al.* 2018, Naghipour *et al.* 2020). In order to test logistical providers third party, Zhang *et al.* (2018) studied a groundbreaking approach for information granulation entropy. Conventional fuzzy assessment approaches are useful but time biased. Objective calculations are logical, but their findings are also hard to understand (Moayedi *et al.* 2020a, b, c, Oyarhossein *et al.* 2020). In order to facilitate clustering precision, the new modularity model Q based on low complexity and improved accuracy of information entropy (IE) is proposed. The IE algorithm achieves stronger group identification results than the GN and Fast GN algorithms in networks with a clear community structure and an unspecified community structure, while computational complexity decreases (Xiaolong *et al.* 2012, Habibi *et al.* 2018a, b, Ebrahimi *et al.* 2019, Hashemi *et al.* 2019, Zhou *et al.* 2020). A complexity model of non-serial production processes was developed by Duan *et al* on the basis of the entropy model system-angle information theory. The entropy weight protocol involves the following steps: Create a factor evaluation method, create the eco-safety classification factor, construct an entropy model, and evaluate the material components, measure the significance of the eco-security factor with the earth and calculate the weight of all variables (Jia and Zhao 2010, Nangreave *et al.* 2011, Yu *et al.* 2012).

2. Problem statement

While vision-based object tracking methods for the analysis of sport competitive videos have been developed, it is still difficult to accurately identify and position a small fast ball. In this article, a DP network was built based on information entropy to address these challenges for better understanding of the athletes' success of tennis motion tracking from a dynamic perspective. Using traditional methods in object's recognition, such as HOG, SIFT, etc could provide poor accuracy in motion tracking objectives.

3. Methodology

We have marked 20,844 images of men's individual final at the Indonesian Open Final to test the proposed network. VGG16 is used to test the output of the proposed consecutive input frame technique. A detailed analysis of various models is carried out beside the traditional image recognition method. In addition, in order to avoid the notorious overfitting problem that often arising in deep learning solutions, the testing dataset includes additional

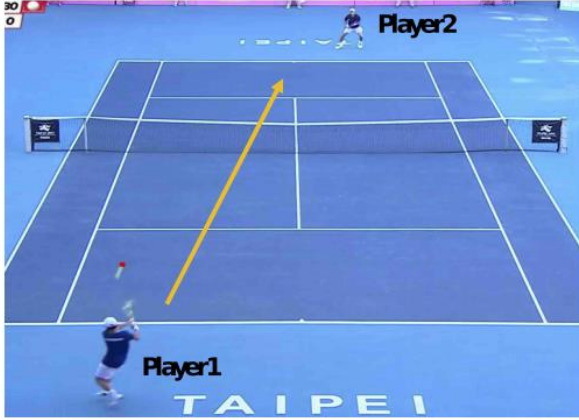


Fig. 12 Sample of prolonged tennis trace

Table 1 CNN and three logic rules for tennis motion tracking data analysis

Models	F1-Score	Precision	Recall
CNN	77.13	75.36	79.00
Pretrained	80.67	79.28	82.11
Pretrained+ but rule	81.95	80.84	83.09
Pretrained+ switch from rule	80.92	79.74	82.14
pretrained+ switch to rule	82.60	80.89	84.39
Pretrained+ All the 3 rule	83.85	82.56	85.18

data from 9 tennis games on various courts, comprising a hard court, grass court, and Red Tile Court. Tennis tracking by VGG16 was assessed to explore model extensibility. Regarding the length (75 minutes), resolution (1280 × 720) and frame rate (30 fps) of the video, 81 game-related clips are segmented by screening unrelated images while each capture a full action, beginning with the ball. The cumulative number of frames is 20, 844. The following features are available for each frame: “Frame Name,” “Class of Visibility,” “X,” “Y”, and” Trajectory Pattern”.

The name of the frame file is “Frame Name.” “Visibility Class” in short, VC for each frame signifies ball visibility. The values 0, 1, 2, and 3 are probable. VC = 0 indicates that the ball is not inside the circle. VC = 1 ensures that it is easy to locate the ball. VC=2 means that the ball is in the picture, but cannot be detected easily. For instance, the 0060 jpg ball (Fig. 4) is invisible due to its similarity of color with the “Taipei” on court. However, this undefined ball position could be clear by its neighboring frames, 000059 and 0061.

4. Convolutional neural networks

Artificial intelligence as a powerful method are used in different applications such as engineering, health care, pattern recognition, image processing etc. (Liu *et al.* 2021e, Moradi *et al.* 2021). CNN as a type of artificial neural network maps between temporally and spatially distributed arrays in arbitrary dimensions that seems proper to use in video, images or time series (Toghroli *et al.* 2014, Safa *et*

al. 2016, Sedghi *et al.* 2018, Katebi *et al.* 2019, Shariati *et al.* 2020e). CNNs are divided as local connectivity, translation invariance and an optional progressive decrement in spatial resolution, which make CNN act as an interconnected filter system (Cheshmeh *et al.* 2020, Shariati *et al.* 2020b, 2021a, Shi *et al.* 2020, Xu *et al.* 2021). Profitable comparisons might be produced among other filtering frameworks, because the neural weights of a CNN work as the system taps of wavelet filters or finite impulse response (FIR) (Mohammadhassani *et al.* 2013, Toghroli *et al.* 2016, Sadeghipour Chahnasir *et al.* 2018, Safa *et al.* 2020, Shariati *et al.* 2020g). Then, a developed CNN might be considered of trainable filter system, custom produced for a specific function mapping usage (Shariati *et al.* 2011b, 2016, 2019a, Sinaei *et al.* 2011, Shahabi *et al.* 2016, Khorramian *et al.* 2017, Yu *et al.* 2022). Ultimately, CNNs permit the processes of huge spatially distributed arrays without a correspondingly many free factors while raising the chances of minima generalization and avoidance (Fazaeli *et al.* 2016, Ghazanfari *et al.* 2016, Habibi *et al.* 2016, Hosseini *et al.* 2018). At first, one single hidden layer and one dimensional input are explained. Multiple layers and multiple dimensions might be involved in the extensions with possible activity of down-sampling (Shariati *et al.* 2020a, Huang *et al.* 2021b, Ma *et al.* 2021a, Zhao *et al.* 2021). Acquiring the formula to change the weight and bias factors of one CNN provide a training set of input output pairs $\xi_{k,r}^\mu, \zeta_{i,p}^\mu$. In CNN, translated neurons $h_{j,q}^\mu$ gain only the local connections from the prior layer. The weights of a CNN are invariant to spatial translation, so the weights are $w_{j,k}^t, t = \{-T, \dots, 0, \dots, T\}$ connecting feature array $V_{j,q}^\mu$ and input array $\xi_{k,r}^\mu$. $2T + 1$ is the size of area surrounding each translation point for which network weights exist like the filter size.

$$h_{j,q}^\mu = \sum_k \sum_t w_{j,k}^t \xi_{k,q+t}^\mu + b_j$$

$\{i, j, k\} =$ the neuron arrays in output, hidden, and input layers
 $\{p, q, r\} =$ a spatial index for each layer
 $\mu =$ input pattern
 $j =$ hidden unit
 $q =$ net input

(1)

The index to $\xi_{k,r}^\mu$ is clamped to spatially nearby place centered at translation q by setting $r = q + t$.

$$b_j = \text{usual constant bias}$$

The neural output makes the hidden feature arrays done by transfer performance

$$V_{j,q}^\mu = g(h_{j,q}^\mu) \quad (2)$$

In output layer, the neuron at translation p in i^{th} array receives net input

$$h_{i,p}^\mu = \sum_j \sum_s w_{i,j}^s V_{j,p+s}^\mu + b_i \quad (3)$$

$s = \{-S, \dots, 0, \dots, S\}$ and $2S + 1$ is the length of filter in output layer, also the relative indexing was replaced for absolute indexing $q = p + s$. Ultimate output is

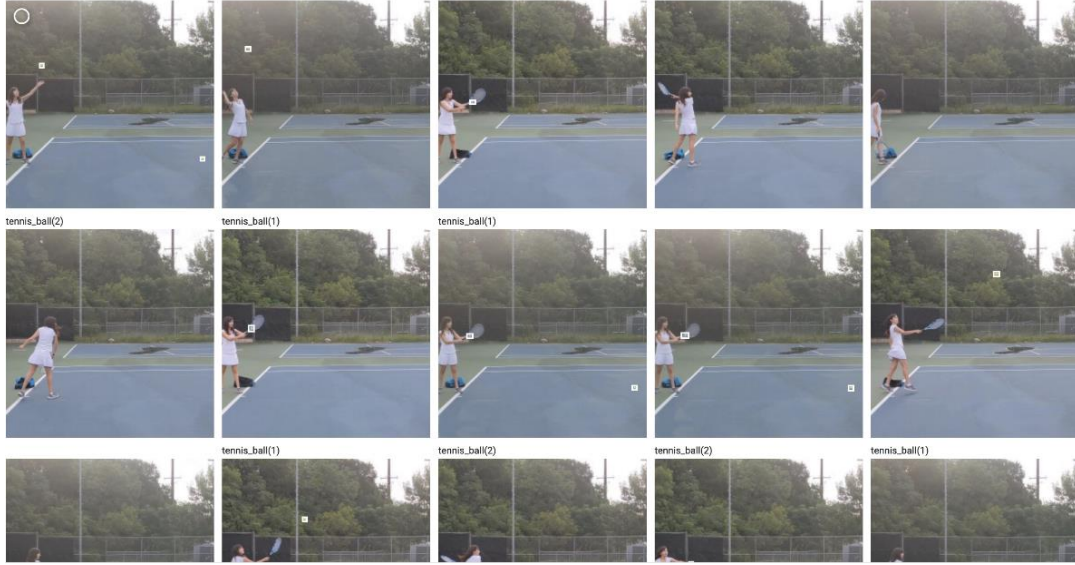


Fig. 14 Using machine learning in tennis motion tracking

$$O_{i,p}^u = g(h_{i,p}^u) = g\left(\sum_j \sum_s w_{i,j}^s V_{j,p+s}^u + b_i\right) \quad (4)$$

$$O_p = f(\xi_{p-s-T}, \dots, \xi_p, \dots, \xi_{p+s+T}).$$

4.1 Delta rule for CNNs

Though CNNs applied the same weight update rule as normal NN, there is a need to care more, especially with differential indexing of feature maps and spatial translation. Regarding the normal ANNs, the CNN's cost function is:

$$E = \frac{1}{2} \sum_{\mu,i,p} [\zeta_{i,p}^u - O_{i,p}^u]^2 \quad (5)$$

Derivative of the error was gained regarded the s^{th} weight of filter joining the i^{th} output array to j^{th} feature array.

$$\frac{\partial E}{\partial w_{i,j}^s} = - \sum_{\mu,p} [\zeta_{i,p}^u - g(h_{i,p}^u)] g'(h_{i,p}^u) V_{j,p+s}^u \quad (6)$$

Used in combination with the familiar gradient descent weight update rule

$$\Delta w_{i,j}^s = \eta \sum_{\mu,p} \delta_{i,p}^u V_{j,p+s}^u \quad (7)$$

where

$$\delta_{i,p}^u = [\zeta_{i,p}^u - g(h_{i,p}^u)] g'(h_{i,p}^u) \quad (8)$$

For finding the weight alteration of input to hidden connections $w_{j,k}^s$, delta rule is used with a indices' change

$$\Delta w_{j,k}^s = \eta \sum_{\mu,p} \delta_{j,q}^u \xi_{k,q+t}^u \quad (9)$$

$$\delta_{j,q}^u = \sum_s g'(h_{j,q}^u) \sum_i \delta_{i,q-s}^u w_{i,j}^s \quad (10)$$

Bias terms b_i and b_j are treated as normal weights with constant input, and might be updated applying Eqs. (10) and (11).

4.2 VGG-16

Simonyan and Zisserman (2014) suggested a convolution neural network of VGG16. The architecture of ImageNet is simple and commonly used. It takes an image of 224×224 px as input and vector of size 1000. VGG16 comprises 13 overlays, 3 fully connected layers and five layers of pooling (Fig. 14). In the 16 convolution layers, features from the ImageNet can be removed. We have a multiple filter of 3×3 at each convolution layer with 1 px a stride. For sorting, the last layer softmax is used. ReLU is used as an activation feature in any convolution layer. DP algorithms need a massive dataset and a long time to train the various weights and millions of deep network factors. This enables consistency in the portrayal of information. Next, an expansion of the datasets is feasible with the data augmentation process. Similar training and testing dataset (same function and same distribution) is also required. In reality, joining these variables is challenging and costly. The researchers are designing their own method and this takes a long time. At this point, transfer learning is a solution that reduces effort that guarantees a correct classification with lower samples (Akram *et al.* 2018).

The transfer learning of an Artificial Intelligence (AI) model is to convey knowledge from a relative domain, which is characterized as a capacity of system to identify and adapt learning and skills in earlier tasks to new fields and tasks (Pan and Yang 2010) with commonalities (Fig. 15). A method of transfer learning is especially important for classifying and sound reduction through various deep architectures trained in Deep Convolution Neural Networks environment (Aghakhani *et al.* 2015). DP networks could learn through transmission learning very challenging associations resulting the overfitting. Certain approaches

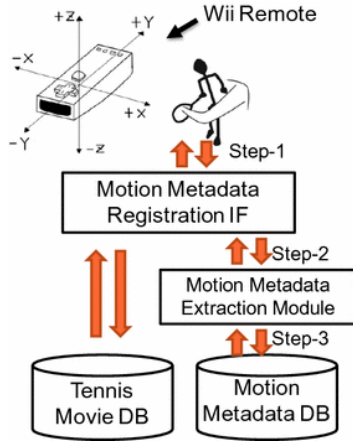


Fig. 15 Tennis swing motion in machine learning

exist to minimize this, such as regularization and dropout. If the training data collection is really too limited, there is an obvious chance to use the augmentation methods. It is a question of making such variants on the same image by slight mathematical transformations on the geometric structure (e.g. rotation or translation). This is helpful if neural networks are not to be over fitted and improve their predictive ability. Two methods to transition learning can be used (Akram *et al.* 2018, Shahin *et al.* 2019): Fine tuning and extraction of functions. All of these elements depend on the scale and similarity of the dataset:

Feature retrieval: the extraction of images from new datasets includes the use of features of a pre-trained network. These features trains a new classifier. Extracting the function makes sense in case of a wide set of difficult data variables. A few top layers of a frozen model for role extraction are extracted. In addition, all parameters (with the exception of the last) for the pre-trained network are initialized and the testing would be completed faster if the initialization was randomly performed.

The model achieves 92.7% top 5 test accuracy in ImageNet. VGG16 was trained and used the Titan Black GPUs from NVIDIA. The input to Cov1 is a 224 x 224 RGB image of fixed format. The images are transferred by a stack of convolutional layers where filters were used in a very narrow area of reception (3 x 3).

4.3 Entropy

The human movement variability can be described as motor performance variations over multiple repetitions for the same task (Zhang *et al.* 2018). Despite similarities between repetitions, the multiple constraints inherent to the environment, the task and even the athlete's body, lead to inevitable differences, thus resulting in a certain degree of variability (Krizhevsky *et al.* 2012). From an evaluation perspective, the human movement oscillations can be evaluated as any other time-series by benefiting from entropy-based techniques (Gu *et al.* 2018), which allow to identify the variability in a spatio-temporal perspective. Despite the multiple entropy based techniques, one may consider to measure sports variability both Shannon's entropy (Gao *et al.* 2020) and approximate entropy (ApEn).

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The techniques for estimating the approximate entropy can be considered as a process represented by a time-series and related statistics. Let us consider that the whole data of t samples (i.e., seconds) is shown by a time-series as $u(1), u(2), \dots, u(N)$, from measurements equally spread out in time (Van der Maaten and Hinton 2008). These samples form a sequence of vectors $x(1), x(2), \dots, x(N - m + 1) \in \mathbb{R}^{1 \times m}$, each one was identified by the array $x(i) = [u(i)u(i + 1) \dots u(i + m - 1)] \in \mathbb{R}^{1 \times m}$. Parameters N_t , m and ε should be stationary for each calculation.

$N =$ the length of time-series (i. e., number of data points of the whole series),

$m =$ the length of comparable sequences

$\varepsilon =$ the tolerance for accepting matches

$$C_i^m(\varepsilon) = \frac{\text{number of } x(j) \text{ such that } d(x(i), x(j)) \leq \varepsilon}{N - m + 1} \quad (11)$$

for $1 \leq i \leq N - m + 1$. Based on Takens' work Eq. (11), it could define the distance $d(x(i), x(j))$ for vectors $x(i)$ and $x(j)$ as:

$$d(x(i), x(j)) = \max_{k=1, 2, \dots, m} |u(i + k - 1) - u(j + k - 1)| \quad (12)$$

From the $C_i^m(\varepsilon)$, it is possible to define (11):

$$C_i^m(\varepsilon) = (N_c - m + 1)^{-1} \sum_{i=1}^{N_c - m + 1} C_i^m(\varepsilon), \quad (13)$$

and the correlation dimension as:

Table 2 motion velocity ratio

Estimate	Manual Tracking		Automatic Tracking	
	Hela-R	Hela-L	Hela-R	Hela-L
Velocity	0.72±0.23	0.83±0.35	0.75±0.28	0.80±0.31
Fast motion ratio	0.23	0.27	0.21	0.28
Slow to fast probability	0.09	0.10	0.08	0.12
Fast to slow probability	0.27	0.22	0.28	0.22

$$\eta_m = \lim_{\varepsilon \rightarrow 0, N \rightarrow \infty} \frac{\ln(C^m(\varepsilon))}{m \ln \varepsilon}, \quad (14)$$

The limit in (Hernández-García and König 2018) exists for many chaotic attractors and this process is used to test data. Indeed, a “scaling range” of ε values is searched for which $\frac{\ln(C^m(\varepsilon))}{m \ln \varepsilon}$ is roughly stable for large m , showing the correlation dimension of this ratio.

$$\Phi^m(\varepsilon) = (N_c - m + 1)^{-1} \sum_{i=1}^{N_c - m + 1} C_i^m(\varepsilon), \quad (15)$$

One can define the approximate entropy as:

$$ApEn = \Phi^m(\varepsilon) - \Phi^{m+1}(\varepsilon) \quad (16)$$

A preliminary conclusion suggests that choice of the standard deviation of the data ε ranging from 0.1 to 0.2 would produce reasonable statistical validity of $ApEn$ (Van der Maaten and Hinton 2008).

4.4 Details of unascertained measurement (UM) model

4.4.1 Determining evaluation space

Suppose that Γ has n objects, and $\Gamma = (\Gamma_1, \Gamma_2, \dots, \Gamma_n)$. Each object of Γ_i ($i = 1, 2, \dots, n$) has m evaluating indicators, so $\Psi = (\Psi_1, \Psi_2, \dots, \Psi_m)$. Then Γ_i can be represented as m -dimensional $\Gamma_i = (\varphi_i^1, \varphi_i^2, \dots, \varphi_i^m)$. with respect to evaluate index φ_i^j . For each φ_i^j ($i = 1, 2, \dots, n, j = 1, 2, \dots, m$), p evaluation grades of $(\Delta_1, \Delta_2, \dots, \Delta_p)$. Regarding that the evaluation space is θ , $\theta = (\Delta_1, \Delta_2, \dots, \Delta_p)$. Suppose Δ_k ($k = 1, 2, \dots, p$) is the k -th evaluation grade, and the k -th grade is higher than that of the $(k+1)$ -th one, denoted as $\Delta_k > \Delta_{k+1}$. If the grading rank $(\Delta_1, \Delta_2, \dots, \Delta_p)$ satisfies $\Delta_1 > \Delta_2 > \dots > \Delta_{k+1}$ or $\Delta_1 < \Delta_2 < \dots < \Delta_{k+1}$, $(\Delta_1, \Delta_2, \dots, \Delta_p)$ is named the ordered partition class of evaluation space θ .

$$\varphi_i^j = \text{measured value of evaluation object (Ri)}$$

$$\mu_{ij3} = \begin{cases} 0 & x_{ij} \leq 60 \text{ or } x_{ij} > 82.5 \\ \frac{x_{ij} - 60}{7.5} & 60 < x_{ij} \leq 67.5 \\ \frac{82.5 - x_{ij}}{15} & 67.5 < x_{ij} \leq 82.5 \end{cases} \quad (17)$$

$$\mu_{ij4} = \begin{cases} 1 & x_{ij} \leq 60 \\ \frac{67.5 - x_{ij}}{7.5} & 60 < x_{ij} \leq 67.5 \\ 0 & x_{ij} > 67.5 \end{cases} \quad (18)$$

4.4.2 UM of single index

UM is shown as $v_{ik}^j = v(x \in c_k)$, v_{ik}^j is the degree of v_{ik}^j belonging to the k -th evaluation grade of C_k , satisfying the following principles

1) Nonnegative and limited principle

$$0 \leq v(\varphi_i^j \in \Delta_k) \leq 1 \quad (19)$$

2) Convergent principle

$$v(\varphi_i^j \in \theta) = 1 \quad (20)$$

3) Additive principle

$$v\left[\varphi_i^j \in \bigcup_{s=1}^k \Delta_s\right] = \sum_{s=1}^k \varphi_i^j \in \Delta_s(1, 2, \dots, p) \quad (21)$$

These three concepts need to be fulfilled together as a UM, unless, they can be considered an estimate. The Single Index UM matrix is

$$(v_{ik}^j)_{m \times p} = \begin{bmatrix} v_{i1}^1 & v_{i1}^2 & \cdots & v_{i1}^p \\ v_{i2}^1 & v_{i2}^2 & \cdots & v_{i2}^p \\ \vdots & \vdots & \cdots & \vdots \\ v_{im}^1 & v_{im}^2 & \cdots & v_{im}^p \end{bmatrix} \quad (22)$$

UM function is

$$\begin{cases} \mu_i(x) = \begin{cases} \frac{-x}{\beta_{i+1} - \beta_i}, & \beta_i < x \leq \beta_{i+1} \\ 0, & x > \beta_{i+1} \end{cases} \\ \mu_i(x) = \begin{cases} 0, & x \leq \beta_i \\ \frac{-x}{\beta_{i+1} - \beta_i} - \frac{\beta_i}{\beta_{i+1} - \beta_i}, & \beta_i < x \leq \beta_{i+1} \end{cases} \end{cases} \quad (23)$$

4.4.3 Identification weight of index

By knowing the membership of each index, the “importance” of the weight has one interpretation, the importance for the index data classifying to define the class of index if w_j equals the relative important extent of measured index Ψ_j is juxtaposed with other indicators. w_j satisfies $0 \leq w_j \leq 1$, and $\sum_{j=1}^m w_j = 1$ as the weight of Ψ_j .

The weight vector $w = (w_1, w_2, \dots, w_m)$.

w_j is:

$$x_i = 1 + \frac{1}{\ln p} \left(\sum_{j=1}^p v_{ji} \ln v_{ji} \right) \quad (24)$$

$$w_j = x_i \sum_{i=1}^n x_i \quad (25)$$

where $0 \leq x_i \leq 1$.

The evaluation matrix of UM of single index is known, so w_j can be obtained by Eqs. (9) and (10).

$$\mu_{ij4} = \begin{cases} 1 & x_{ij} \leq 60 \\ \frac{67.5 - x_{ij}}{7.5} & 60 < x_{ij} \leq 67.5 \\ 0 & x_{ij} > 67.5 \end{cases} \quad (26)$$

Table 3 Results for the average number of fixations (numFix) and fixation duration in case of the single objects for the manual (ELAN) and automatic (VEV) annotation

Object (3 trials per Object)	Manual annotation							
	Object		Hand		Object		Hand	
	numFix	fixDur	numFix	fixDur	numFix	fixDur	numFix	fixDur
cup 1	7	6693	1	125	8	5550	2	780
cup 2	6	4644	1	279	7	4890	2	920
cup 3	8	6031	2	570	11	3940	2	1230
sphere 1	5	7442	0	0	5	7210	1	290
sphere 2	7	5806	3	1222	8	4850	4	1000
sphere 3	7	7289	1	309	7	6720	1	370
stapler 1	7	4594	4	1647	8	3130	4	2070
stapler 2	5	3063	4	2283	5	2110	3	1570
stapler 3	3	3312	4	2183	6	2560	6	2520

4.4.4 Composite UM of multiple indices

v_{ik} shows the degree of assessment object Γ_i belongs to k -th grade of evaluation (Δ_k). If v_{ik} is equal to $v(\Gamma_i \in \Delta_k)$, v_{ik} is termed the composite UM of multiple indices (Zhu *et al.* 2018). After gaining the identification weight and single index matrix, considering the meaning of identification weight, the composite UM of multiple indices can be written as

$$v_{ik} = \sum_{j=1}^m \omega_j v_{ik}^j \quad (i = 1, 2, \dots, n, k = 1, 2, \dots, p) \quad (27)$$

where v_{ik} satisfies $0 \leq v_{ik} \leq 1$ and $\sum_{k=1}^p v_{ik} = \sum_{k=1}^p \sum_{j=1}^m \omega_j v_{ik}^j = \sum_{j=1}^m (\sum_{k=1}^p v_{ik}) \omega_j = 1$

4.4.5 Principle of identification

Since Δ_k is "better" than Δ_{k+1} , the classification of comment ranks ($\Delta_1, \Delta_2, \dots, \Delta_p$) is ordered say the highest measure identification (MMI) principle is not available. The credible degree identification (CDI) principle is needed. Let the credible identification be λ , where $0.5 \leq \lambda \leq 1$, and it is always 0.6 or 0.7 (Zhou and Li 2012). If the e valuation space meets $\Delta_1, \Delta_2, \dots, \Delta_p$, Let

$$k_0 = \min \left\{ k: \sum_{s=1}^k v_{is}(\Delta_i) \geq \delta, 1 \leq k \leq p \right\} \quad (28)$$

$\varphi_i =$ the k_0 -section appraisal grade Δ_{ki}

The confidence that the grade of φ_i is not higher than k_0 is λ or the confidence that the grade of sample φ_i is higher than k_0 is $1 - \lambda$. Suppose that the score value of C_t is I_t , J_{Δ_i} is (Feng *et al.* 2020):

$$J_{\Delta_i} = \sum_{i=1}^p I_t \cdot \mu_{it}$$

$J_{\Delta_i} =$ the unascertained superiority degree of evaluation object Δ_i , (29)

$\omega_j = (J_{\Delta_1}, J_{\Delta_2}, \dots, J_{\Delta_i}) =$ vector of unascertained superiority degree

Δ_i (the superiority degree) is ordered according to the magnitude of J_{Δ_i} .

$$\begin{cases} \mu_i(x) = \begin{cases} \frac{1}{2} - \frac{1}{2} \sin \frac{\pi}{a_{i+1} - a_i} \left(x - \frac{a_{i+1} + a_i}{2} \right) & a_i < x \leq a_{i+1} \\ 0 & x > a_{i+1} \end{cases} \\ \mu_{i+1}(x) = \begin{cases} 0 & x \leq a_i \\ \frac{1}{2} + \frac{1}{2} \sin \frac{\pi}{a_{i+1} - a_i} \left(x - \frac{a_{i+1} + a_i}{2} \right) & a_i < x \leq a_{i+1} \end{cases} \end{cases} \quad (30)$$

$$H_j = -t \sum_{k=1}^p q_{ijk} 1nq_{ijk} \quad (31)$$

$$\omega = \frac{d_j}{\sum_{j=1}^m d_j} = \frac{1 - H_j}{m - \sum_{j=1}^m H_j} \quad (32)$$

$$\mu_{ij} = \sum_{j=1}^m \omega_j \cdot \mu_{ij} \quad (i = 1, 2, \dots, n, k = 1, 2, \dots, p) \quad (33)$$

$$p_0 = \min \left| p: \sum_{k=1}^p \mu_{ik} > \lambda i, i = 1, 2, \dots, n \right| \quad (34)$$

$$\mu_{ij1} = \begin{cases} 0 & x_{ij} \leq 82.5 \\ \frac{x_{ij} - 82.5}{7.5} & 82.5 < x_{ij} \leq 90 \\ 1 & x_{ij} > 90 \end{cases} \quad (35)$$

$$\mu_{ij2} = \begin{cases} 0 & x_{ij} \leq 67.5 \text{ or } x_{ij} > 90 \\ \frac{x_{ij} - 67.5}{15} & 76.5 < x_{ij} \leq 82.5 \\ \frac{90 - x_{ij}}{7.5} & 82.5 < x_{ij} \leq 90 \end{cases} \quad (36)$$

5. Conclusions

In this study, the use of a deep CNN with VGG16 for the tennis motion tracking was analyzed. Firstly, we have extracted the features and then classified the images using

CNN-VGG16 classifier. Training the data set took for about 24 hours. After training the code, desired output image was taken. In VGG16, high speed coordinates and small objects as tennis can be accurately positioned. VGG 16 makes detailed estimates of sport videos transmitted without a high resolution and frame ratio, minimizing dramatically the costs of capturing and editing high-specification videos. A scalable input was developed enabling CNN-VGG 16 to feed with many consecutive input frames to improve the ability of VGG 16 to recognize the trajectory patterns of fast-moving objects. By assessing the standard image processing algorithm, as well as the CNN-VGG 16 proposed on the real tennis video dataset, it was shown that CNN-VGG 16 could gain outstanding prediction efficiency with consecutive input frames on DP network. CNN-VGG 16 uses images in scale 640/360 to create a heat map from either one frame or multiple frames consecutive to locate the ball and also in the public domain footage to achieve high precision. The performance of CNN-VGG 16 are respectively 99.6%, 96.63% and 99.5%. Regarding that CNN-VGG16 is a traditional image processing algorithm, results showed that CNN outperforms the standard approach by a wide margin, achieving outstanding ball follow-up efficiency. Experiments reveal that CNN-VGG16 enhances the traditional image recognition algorithm and efficiently locates fast-moving tennis balls from sports broadcast images. In addition, CNN- VGG 16 achieves a good tracking capability based on our experimental observations with even faster objects which demonstrates promising extensibility.

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