

# Goal!! Event detection in sports video

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## Abstract

*Understanding complex events from unstructured video, like scoring a goal in a football game, is an extremely challenging task due to the dynamics, complexity and variation of video sequences. In this work, we attack this problem exploiting the capabilities of the recently developed framework of deep learning. We consider independently encoding spatial and temporal information via convolutional neural networks and fusion of features via regularized Autoencoders. To demonstrate the capacities of the proposed scheme, a new dataset is compiled, composed of goal and no-goal sequences. Experimental results demonstrate that extremely high classification accuracy can be achieved, from a dramatically limited number of examples, by leveraging pre-trained models with fine-tuned fusion of spatio-temporal features.*

## Introduction

Analyzing unstructured video streams is a challenging task for multiple reasons [10]. A first challenge is associated with the complexity of real world dynamics that are manifested in such video streams, including changes in viewpoint, illumination and quality. In addition, while annotated image datasets are prevalent, a smaller number of labeled datasets are available for video analytics. Last, the analysis of massive, high dimensional video streams is extremely demanding, requiring significantly higher computational resources compared to still imagery [11].

In this work, we focus on the analysis of a particular type of videos showing multi-person sport activities and more specifically football (soccer) games. Sport videos in general are acquired from different vantage points and the decision of selecting a single stream for broadcasting is taken by the director. As a result, the broadcasted video stream is characterized by varying acquisition conditions like zooming-in near the goalpost during a goal and zooming-out to cover the full field. In this complex situation, we consider the high level objective of detecting specific and semantically meaningful events like an opponent team scoring a goal. Succeeding in this task will allow the automatic transcription of games, video summarization and automatic statistical analysis.

Despite the many challenges associated with video analytics, the human brain is able to extract meaning and provide contextual information in a limited amount of time and from a limited set of training examples. From a computational perspective, the process of event detection in a video sequence amounts to two fundamental steps, namely (i) spatio-temporal feature extraction and (ii) example classification. Typically, feature extraction approaches rely on highly engineered handcrafted features like the SIFT, which however are not able to generalize to more challenging cases. To achieve this objective, we consider the state-of-the-art framework of deep learning [18] and more specifically the case

of Convolutional Neural Networks (CNNs) [16], which has taken by storm almost all problems related to computer vision, ranging from image classification [15, 16], to object detection [17], and multi-modal learning [6]. At the same time, the concept of Autoencoders, a type of neural network which tries to appropriate the input at the output via regularization with various constrains, is also attracting attention due to its learning capacity in cases of unsupervised learning [21].

While significant effort has been applied in designing and evaluating deep learning architectures for image analysis, leading to highly optimized architectures, the problem of video analysis is at the forefront of research, where multiple avenues are explored. The urgent need for video analytics is driven by both the wealth of unstructured videos available online, as well as the complexities associated with adding the temporal dimension. In this work, we consider the problem of goal detection in broadcasted low quality football videos. The problem is formulated as a binary classification of short video sequences which are encoded through a spatio-temporal deep feature learning network. The key novelties of this work are to:

- Develop a novel dataset for event detection in sports video and more specifically, for goal detection in football games;
- Investigate deep learning architectures, such as CNN and Autoencoders, for achieving efficient event detection;
- Demonstrate that learning, and thus accurate event detection, can be achieved by leveraging information from a few labeled examples, exploiting pre-trained models.

## State-of-the-art

For video analytics, two major lines of research have been proposed, namely frame-based and motion-based, where in the former case, features are extracted from individual frames, while in the latter case, additional information regarding the inter-frame motion, like optical flow [3], is also introduced.

In terms of single frame spatial feature extraction, CNNs have had a profound impact in image recognition, scene classification, and object detection, among others [16]. To account for the dynamic nature of video, a recently proposed concept involves extending the two-dimensional convolution to three dimensions, leading to 3D CNNs, where temporal information is included as a distinct input [12, 13]. An alternative approach for encoding the temporal information is through the use of Long-Short Term Memory (LSTM) networks [1, 13], while another concept involves the generation of *dynamic images* through the collapse of multiple video frames and the use of 2D deep feature extraction on such representations [7]. In [2], temporal information is encoded through average pooling of frame-based descriptors and

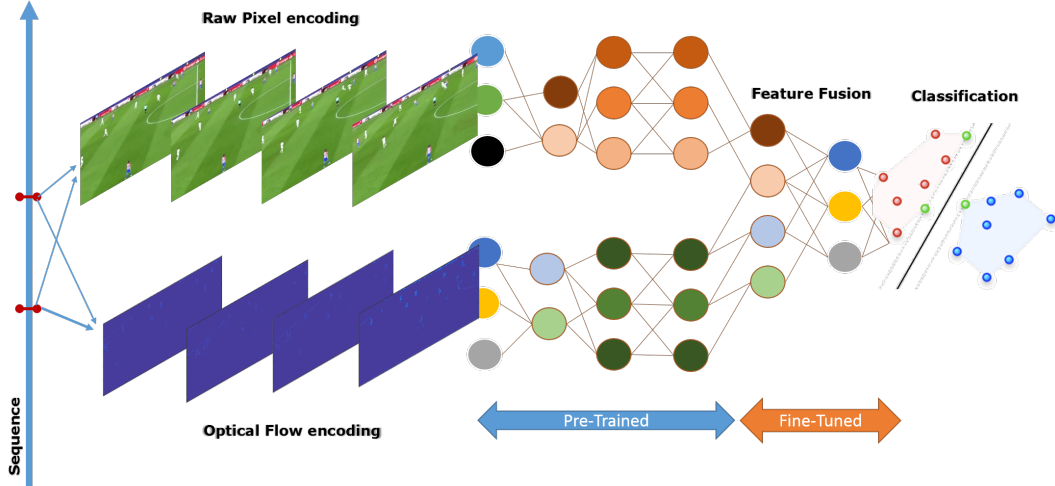


Figure 1: Block diagram of the proposed Goal detection framework. A 20-frame moving window initially selects part of the sequence of interest, and the selected frames undergo motion estimation. Raw pixel values and optical flows are first independently encoded using the pre-trained deep CNN for extracting spatial and temporal features. The extracted features can either be introduced into a higher level network for fusion which is fine-tuned for the classification problem, or concatenated and used as extended input features for the classification.

the subsequent encoding in Fisher and VLAD vectors. In [4], the authors investigated deep video representation for action recognition, where temporal information was introduced in the *frame-diff* layer of the deep network architecture, through different temporal pooling strategies applied in patch-level, frame-level, and temporal window-level.

One of the most successful frameworks for encoding both spatial and temporal information is the two-stream CNN [8]. Two-stream networks consider two sources of information, raw frames and optical flow, which are independently encoded by a CNN and fused into an SVM classifier. Further studies on this framework demonstrated that using pre-trained models can have a dramatic impact on training time, for the spatial and temporal features [22], while convolutional two-stream network fusion was recently applied in video action recognition [23]. The combination of 3D convolutions and the two-stream approach was also recently reported for video classification, achieving state-of-the-art performance at significantly lower processing times [24]. The performance demonstrated by the two-streams approach for video analysis led to the choice of this paradigm in this work.

## Event Detection Network

The proposed temporal event detection network is modeled as a two-stream deep network, coupled with a sparsity regularized Autoencoder for fusion of spatial and temporal data. We investigate Convolutional and Autoencoder Neural Networks for the extraction of spatial, temporal and fused spatio-temporal features and the subsequent application of kernel based Support Vector Machines for the binary detection of goal events. A high level overview of the processing pipeline is shown in Figure 1.

While in fully-connected networks each hidden activation is computed by multiplying the entire input by the corresponding weights in that layer, in CNNs each hidden activation is computed by multiplying a small local input against the weights. The typical

structure of a CNN consists of a number of convolution and pooling/subsampling layers, optionally followed by fully connected layers. At each convolution layer, the outputs of the previous layer are convolved with learnable kernels and passed through the activation function to form this layer's output feature map.

Let  $n \times n$  be a square region extracted from a training input image  $\mathbf{X} \in \mathbb{R}^{N \times M}$ , and  $\mathbf{w}$  be a filter of kernel size  $(m \times m)$ . The output of the convolutional layer  $\mathbf{h} \in \mathbb{R}^{(n-m+1) \times (n-m+1)}$  is given by:

$$\mathbf{h}_{ij}^{\ell} = \sigma \left( \sum_{a=0}^{m-1} \sum_{b=0}^{m-1} \mathbf{w}_{ab} \mathbf{x}_{(i+a)(j+b)}^{\ell-1} + \mathbf{b}_{ij}^{\ell} \right), \quad (1)$$

where  $\mathbf{b}$  is the additive bias term, and  $\sigma(\cdot)$  stands for the neuron's activation unit. Specifically, the activation function  $\sigma$ , is a standard way to model a neuron's output, as a function of its input. Convenient choices for the activation function include the logistic sigmoid, the hyperbolic tangent, and the Rectified Linear Unit. Taking into consideration the training time required for the gradient descent process, the saturating (*i.e.* tanh, and logistic sigmoid) non-linearities are much slower than the non-saturating ReLU function.

The output of the convolutional layer is directly utilized as input to a sub-sampling layer that produces downsampled versions of the input maps. There are several types of pooling, two common types of which are max-pooling and average-pooling, which partition the input image into a set of non-overlapping or overlapping patches and output the maximum or average value for each such sub-region. For the 2D feature extraction networks, we consider the VGG-16 CNN architecture, which is composed of 13 convolutional layers, with five of them being followed by a max-pooling layer, leading to three fully connected layers [9].

Unlike image detection problems, feature extraction in video must address the challenges associated with the variation of the duration of events, in addition to the challenges related to illumi-

nation and viewpoint variability. We fuse the two representations using a sparsity regularized Autoencoder and more specifically, we consider all available training data from all classes as input to the unsupervised Autoencoder for extracting features encoding both spatial and temporal information.

Formally, the Autoencoder is a deterministic feed-forward artificial neural network comprised of an input and an output layer of the same size with a hidden layer in between, which is trained with backpropagation in a fully *unsupervised* manner, aiming to learn an approximation  $\hat{\mathbf{z}}$  of the input which would be ideally more descriptive than the raw input. The feature mapping that transforms an input pattern  $\mathbf{z} \in \mathbb{R}^n$  into a hidden representation  $\mathbf{h}'$  (called code) of  $k$  neurons (units), is defined by the *encoder* function:

$$f(\mathbf{z}) = \mathbf{h}' = \alpha_f(W_1\mathbf{z} + \mathbf{b}_1), \quad (2)$$

where  $\alpha_f : \mathbb{R} \mapsto \mathbb{R}$  is the *activation function* applied component-wise to the input vector. The activation function is usually chosen to be nonlinear; examples include the logistic sigmoid and the hyperbolic tangent.

The activation function is parametrized by a weight matrix  $W_1 \in \mathbb{R}^{k \times n}$  with models the connections between the input and the hidden layer and a bias vector  $\mathbf{b}_1 \in \mathbb{R}^{k \times 1}$ . The network output is then computed by mapping the resulting hidden representation  $\mathbf{h}'$  back into a reconstructed vector  $\hat{\mathbf{z}} \in \mathbb{R}^{n \times 1}$  using a separate *decoder* function of the form:

$$g(f(\mathbf{z})) = \hat{\mathbf{z}} = \alpha_g(W_2\mathbf{h}' + \mathbf{b}_2), \quad (3)$$

where  $\alpha_g$  is the activation function,  $W_2 \in \mathbb{R}^{n \times k}$  is the decoding matrix, and  $\mathbf{b}_2 \in \mathbb{R}^n$  a vector of bias parameters which are learned from the hidden to the output layer.

The estimation of the parameter set  $\theta = \{W_1, \mathbf{b}_1, W_2, \mathbf{b}_2\}$  of an Autoencoder is achieved through the minimization of the reconstruction error between the input and the output according to a specific loss function. Given the training set  $\mathbf{Z}$ , a typical loss function seeks to minimize the normalized sum of squares error, defining the following optimization objective:

$$J_{AE}(\theta) = \frac{1}{m} \sum_{i=1}^m \left\| \frac{1}{2} z^{(i)} - \hat{z}^{(i)} \right\|^2 + \mathcal{R}(z) \quad (4)$$

where  $\hat{x}$  is implicitly dependent on the parameter set  $\theta$ ,  $\|\cdot\|$  is the Euclidean distance, and  $\mathcal{R}(z)$  is a regularization term. Sparse Autoencoders are a special case of the traditional Autoencoders, where the code is constrained to be sparse, *i.e.* only a small fraction of hidden units are activated by the inputs. Signal and model sparsity have had a profound impact on signal processing and machine learning due to their numerous advantages, such as robustness, model complexity, generative and discriminative capabilities, among others [20].

## Dataset

To evaluate the performance of the proposed sports event detection framework, a novel dataset was compiled using video sequences downloaded from a public repository (YouTube.com). For the "Goal" class, 200 sequences of 2-3 second-long videos where extracted, depicting the event of interest under a large number of viewing conditions including camera location, ego-motion,

drastic illumination changes, low quality encoding, motion artifacts, and cluttering, among others. Similarly, for the "NoGoal" class, 200 sequences were also extracted from different games, showing different examples of confusing activities like near-miss shots and fouls. Representative examples of sequences from the dataset are shown in Figure 2.



Figure 2: Example of frames extracted from the Goals (left column) and No Goals (right column) sequences. One can easily observe that typical sequences where a goal is scored are captured with a greater zoom factor compared to generic scenes, introducing artifacts like motion blurring.

## Experimental Evaluation

For generating the reported experimental results, we consider spatial and temporal features from 20 color frames per sequence, extracted using the VGG-16 network. To introduce the temporal aspects, we employ the Lukas-Kanade optical flow estimation with threshold for noise reduction set to 0.009. To make the optical flow compatible with the pixel values, a linear normalization to the [1, 256] range is performed. In the last stage, coupling of the spatial and the temporal sources of information is achieved via a sparsity regularized Autoencoder, where the parameter for probability of neuron activation was set to 0.1, leading to sparse activations.

The features extracted by the VGG-16 network were subsequently introduced for training with three kernel-based SVM classifiers, namely, linear, Gaussian (with  $\sigma = 1$ ), and  $2^{nd}$  order polynomial kernel SVMs. To generate the experimental results,

we utilized the MatConvNet [25] platform and the available pre-trained models including the VGG-16, while for fusion we employed the Matlab Neural Network toolbox, which allowed the execution of the training process on an NVidia K2200 GPU. Performance is reported in terms of the classification error, *i.e.*, the percentage of misclassified sequences.

### Detection using spatial features

In the first section of the experimental results, we investigate the case where 1000-dimensional spatial feature vectors are extracted for each frame. For each sequence, we perform temporal subsampling to 10 and 20 frames and as a result, each sequence is represented using either a 10000 or a 20000 dimensional feature vector. These spatial feature vectors are subsequently introduced to the SVM classifier for training or testing. The key drive for this experiment is to evaluate the impact of the number of frames on the classification accuracy and we report the average of 10 realizations.

Figure 3 presents the classification error as a function of training examples using features extracted from 10 frames per sequence, while Figure 4 considers 20 frames per sequence. Regarding the impact of the number of frames, the results clearly indicate that using a larger number of frames leads to a significantly better and more stable performance. For the linear kernel SVM, we observe that using all the available training examples results in 22% classification error using 10 frames, as opposed to 16% when using 20 frames. As far as the performance of each classifier is concerned, results also indicate that the Gaussian and the Polynomial kernel SVMs achieve the best performance, significantly better compared to the linear kernel case. Based on these findings, in the rest of the reported experiments, we fix the number of frames that are used for feature extraction to 20.

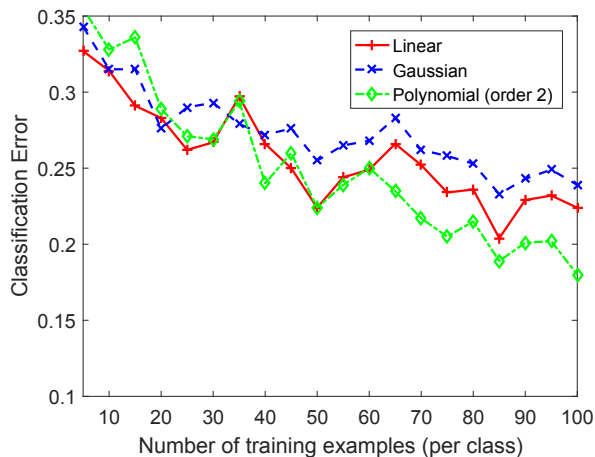


Figure 3: Classification error as a function of training examples using 10 frames per sequence, where only **spatial** features are extracted by the VGG-16 network for three types of SVM kernels.

### Detection using spatial and temporal features

Next, we examine the impact of temporal information when it is encoded through optical flow. Results are shown in Figure 5

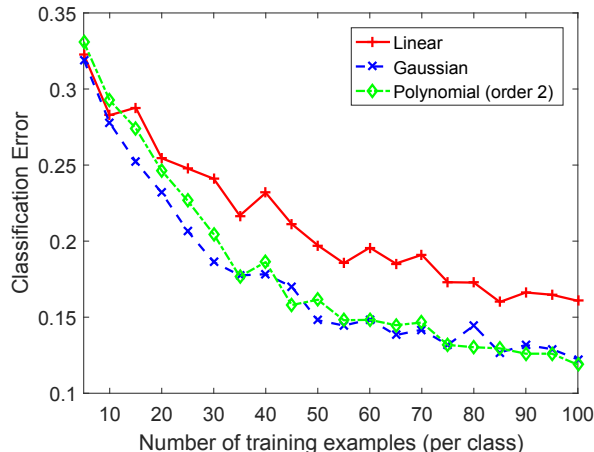


Figure 4: Classification error as a function of training examples using 20 frames per sequence, where only **spatial** features are extracted by the VGG-16 network for three SVM kernels.

for the case of independently introducing spatial and temporal features in the SVM classifier. Comparing the performance between the two cases of inputs, spatial and spatio-temporal, experimental results suggest that temporal information can have a positive impact on detection accuracy. In terms of classifiers, we observe that non-linear kernels, like the Gaussian and the Polynomial, attain a significantly lower classification error, albeit at the cost of extra computational requirements.

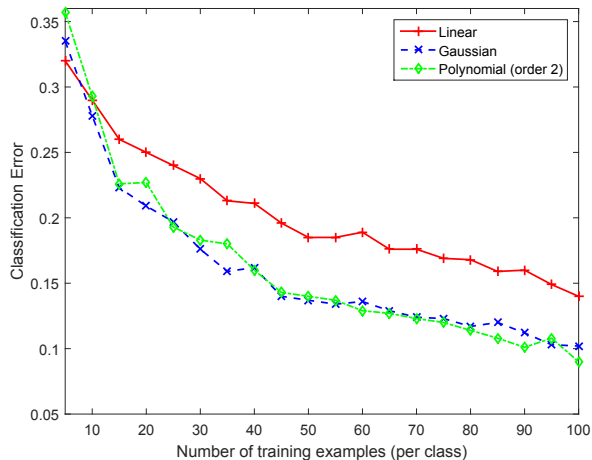


Figure 5: Classification error as a function of training examples, using **spatial** and **temporal** features extracted by the VGG-16 network for three types of SVM kernels.

### Detection using spatio-temporal features

In the last section of the experimental validation, we present the performance of event detection using fused spatio-temporal features. Specifically, the outputs of the independently applied CNNs are concatenated and introduced to a regularized Autoencoder for feature fusion. The Autoencoder is tasked with gener-

ating compact representations, encoding both sources of information, and specifically, reducing the 40000-dimensional input vectors to 400-dimensional ones, two orders of magnitude smaller compared to the ambient dimensionality of the spatial and temporal feature.

Table 1: Classification error for various combinations of classification kernel and features.

Method	Linear	Gaussian	Polynomial
Spatial	0.16	0.12	0.11
Spat. & Temp.	<b>0.14</b>	0.10	0.09
Fused	0.45	<b>0.02</b>	<b>0.03</b>

The results shown in Table 1 report the classification error achieved by all methods, including the case of spatio-temporal features, using all available (100) training examples per class. These results clearly demonstrate the huge potential which can be capitalized by fusion of different sources of information. Particularly, the two most powerful classifiers, the Gaussian and the Polynomial kernel SVM, are able to reduce their classification error almost an order of magnitude, even though the same information is used as input. Most notably, the Gaussian Kernel is able to achieve an impressive 98% classification accuracy using only 100 training examples per class. An additional benefit of the fusion process is the dramatically smaller dimensionality of features extracted per sequence, reducing the requirements and facilitating subsequent analysis like classification.

To illustrate the potential of feature fusion for video analytics, Figure 6 presents the evolution of the value of the Autoencoder cost function during the iterative training process. We observe that that value is monotonically decreasing suggesting that better modeling of the data is achieved with more epochs. In this paper, we limited the maximum number of epochs to 1000 for reasons of computational complexity, although better performance could potential be achieved with a larger number of epochs.

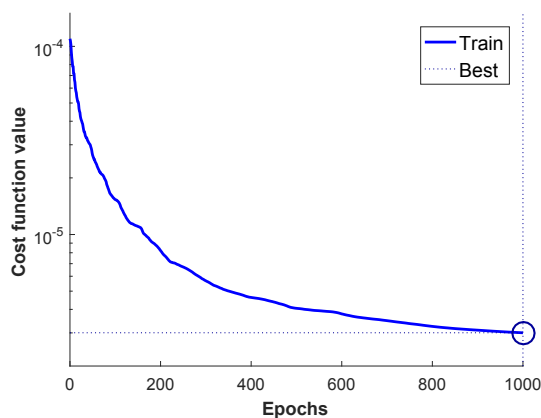


Figure 6: Evolution of the value of the cost function as a function of the number of epochs.

## Conclusions

In this work, we focused our efforts on the design of a learning based architecture for the detection of events (goals) in sports (football) videos. We employed pre-trained convolutional neural networks for extracting both spatial and temporal features and we investigated Autoencoders for fusion of the different information sources. To validate the capabilities of the proposed architectures, a new dataset was compiled while experimental results suggest that very low classification error can be achieved, even from a limited number of training examples. In terms of computational complexity, when pre-trained CNNs are utilized, the most demanding operation is the extraction of the optical flow information. Future work will examine the impact of deep stacked Autoencoders for achieving even higher classification performance.

## Acknowledgments

This work was partially funded by the DEDALE project (contract no. 665044) within the H2020 Framework of the EC.

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