

Temporal Smoothing in 2D Human Pose Estimation for Bouldering

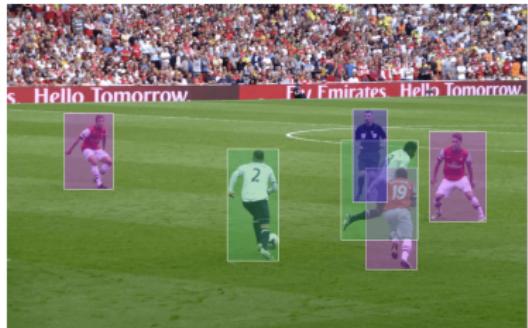
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2023

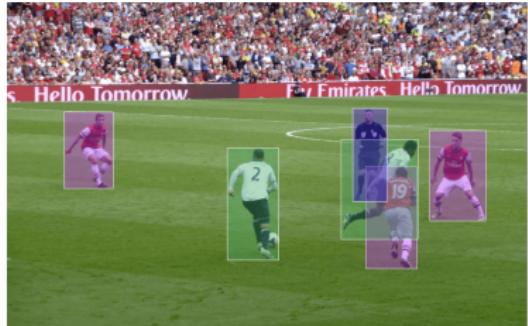
Introduction

- ▶ Increased usage of video analysis in sports.
 - ▶ Help referee
 - ▶ Improve techniques



Introduction

- ▶ Increased usage of video analysis in sports.
- ▶ Often requires the position of the players.
 - ▶ Already developed for popular sports.
 - ▶ Missing for the less popular sports.



Introduction

- ▶ Increased usage of video analysis in sports.
- ▶ Often requires the position of the players.
- ▶ Problems with the data
 - ▶ Methods require large quantities
 - ▶ Unusual poses/movements



Introduction

- ▶ Increased usage of video analysis in sports.
- ▶ Often requires the position of the players.
- ▶ Problems with the data
- ▶ ClimbAlong at NorthTech ApS
 - ▶ Frame-independent pose-detector for bouldering - suboptimal results



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- ▶ Often requires the position of the players.
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- ▶ ClimbAlong at NorthTech ApS
 - ▶ Frame-independent pose-detector for bouldering - suboptimal results
 - ▶ Proposition: Incorporate temporal information



Introduction

- ▶ Aim: extend the ClimbAlong pose-detector to use temporal information.

The Models

- ▶ Generally, three approaches
 1. Convolutional layer
 2. Recurrent neural network (RNN)
 3. Transformer

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- ▶ One of each approach

The Models

Convolutional layer

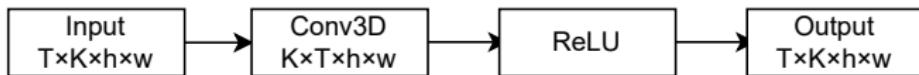
- ▶ Name: 3DConv



The Models

Convolutional layer

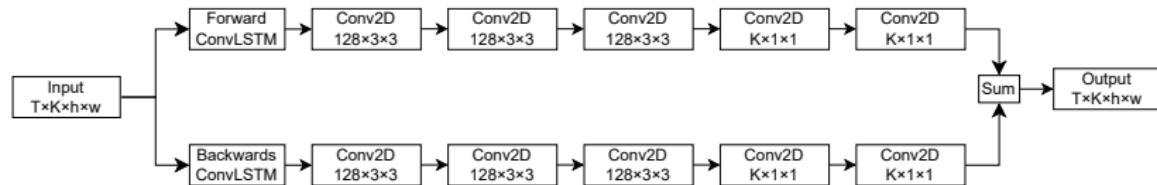
- ▶ Name: 3DConv
- ▶ 3-dimensional conv. layer + ReLU



The Models

RNN-based 1:

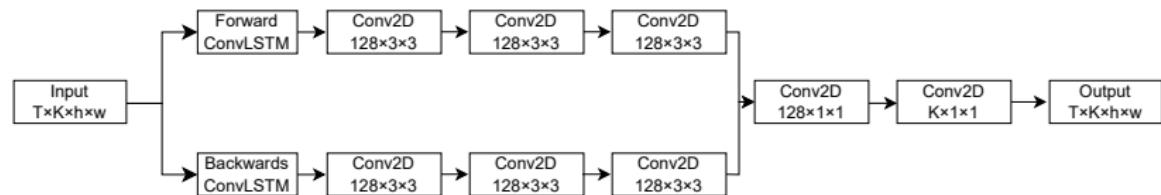
- ▶ Name: bi-ConvLSTM Model S
- ▶ Adaptation of Unipose-LSTM by Artacho and Savakis
- ▶ Bidirectional convolutional LSTM + 3D-conv. layers and ReLUs
- ▶ Processing directions summed together



The Models

bi-ConvLSTM Model C

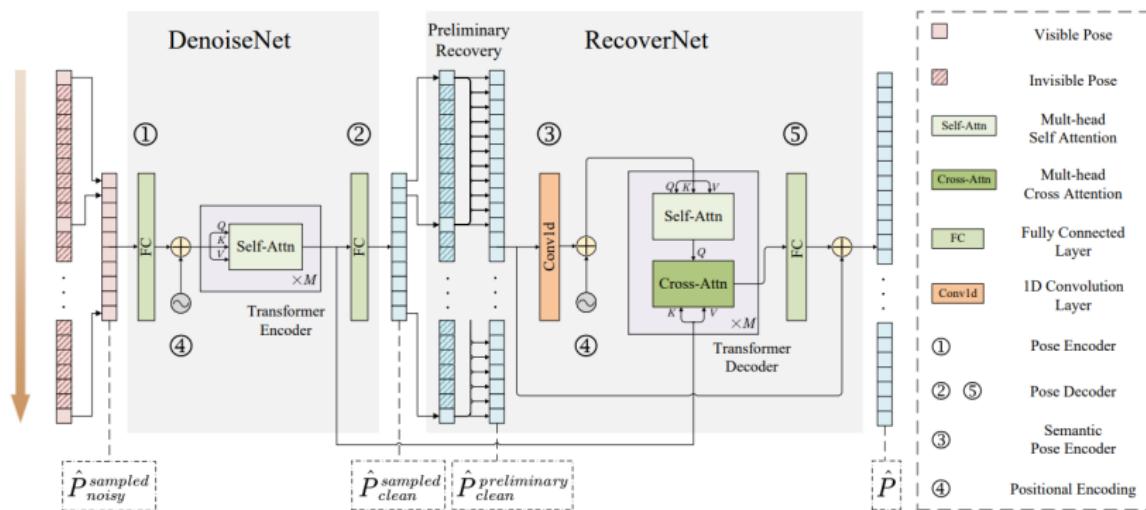
- ▶ Problem: Prioritization of processing direction
- ▶ Solution: Using convolution
- ▶ Otherwise, very similar to bi-ConvLSTM Model S



The Models

DeciWatch by Zeng *Et al.*

- ▶ Transformer-based
- ▶ Samples every n th frame
- ▶ DenoiseNet + RecoverNet



The Data

ClimbAlong

- ▶ Fully annotated videos of climbers



The Data

ClimbAlong

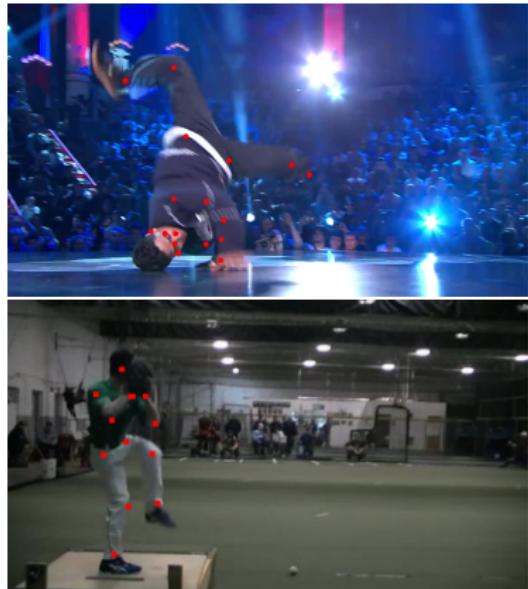
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- ▶ Problem: very small dataset



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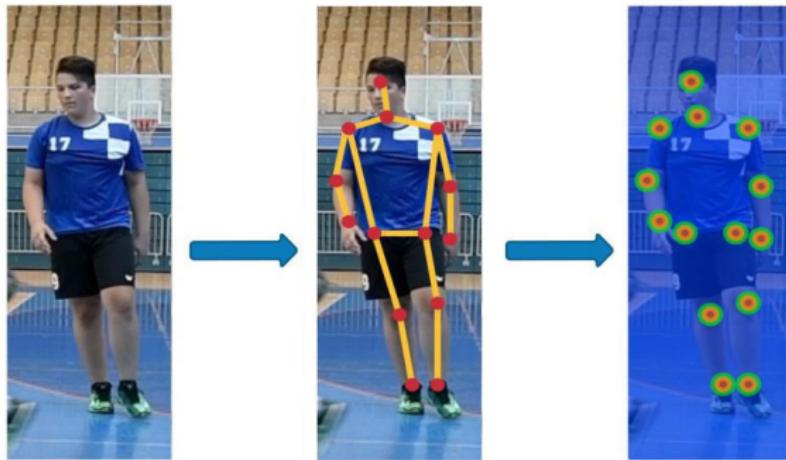
ClimbAlong

- ▶ Fully annotated videos of climbers
- ▶ Problem: Very small dataset
- ▶ Solution: pretrain on related datasets and finetune on ClimbAlong
 - ▶ BRACE
 - ▶ Penn Action



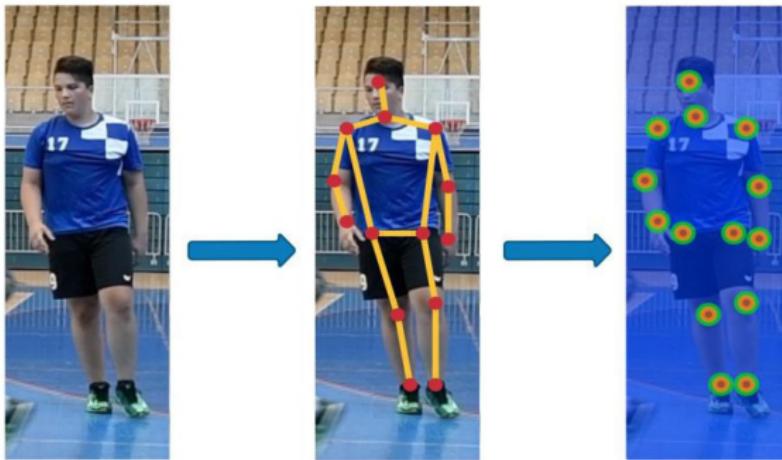
Data Configuration

- ▶ $s = 5$ frames, as suggested by Artacho *Et al.*



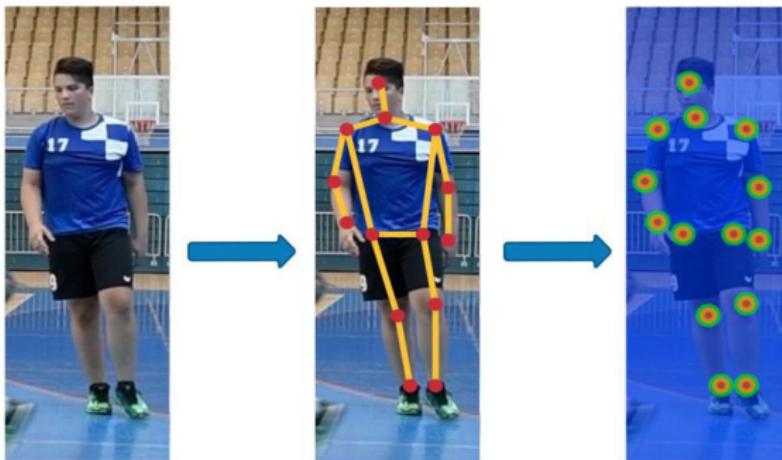
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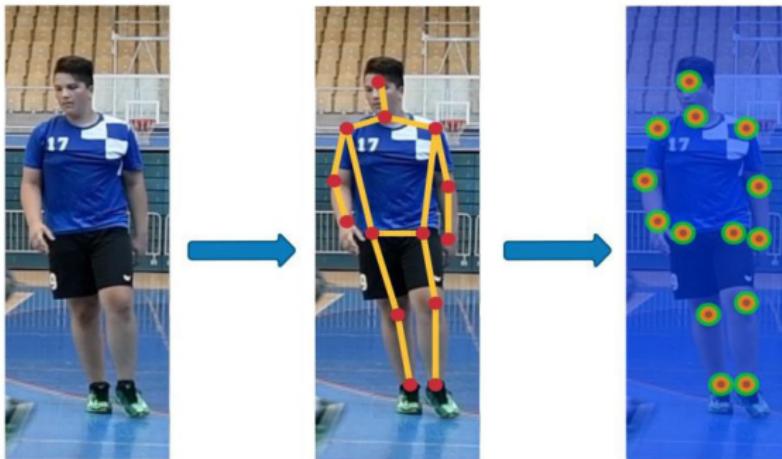
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 2. Model-hyperparameter based on video length



Data Configuration

- ▶ $s = 5$ frames, as suggested by Artacho *Et al.*
 1. Less memory
 2. Model-hyperparameter based on video length
- ▶ Creation of heatmaps



Pretraining

Procedure

- ▶ Not training already-developed pose-detector
 - ▶ Different input images = Unrepresentative pose-detector predictions

Pretraining

Procedure

- ▶ Not training already-developed pose-detector
 - ▶ Different input images = Unrepresentative pose-detector predictions
- ▶ Instead, simulate pose-detector output by shifting keypoints

Pretraining

Finding optimal setting of models

- ▶ Three experiments
 - 1. Various smearing standard deviations: pose-detector does not use fixed standard deviation

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Finding optimal setting of models

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 1. Various smearing standard deviations: pose-detector does not use fixed standard deviation
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 3. Various smearing standard deviations + decreased frame rate: increased context

Pretraining

Finding optimal setting of models

- ▶ Three experiments
 1. Various smearing standard deviations: pose-detector does not use fixed standard deviation
 2. Fixed smearing standard deviation: removed some of randomness from experiment 1
 3. Various smearing standard deviations + decreased frame rate: increased context
- ▶ Two different shifting-scalars

Finetuning

- ▶ Freezing pose-detector
 - 1. Quicker fitting
 - 2. Greater understanding of results

Test results

Only minor difference:

- ▶ Shifting-scalar: shifting-scalar $s = 1$ better simulates the pose-detector
- ▶ Translation + scaling vs only translation: standard deviations of peaks in ClimbAlong data not changing as much

| Accuracy metric | PCK@0.05 | | | PCK@0.1 | | | PCK@0.2 | | |
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| Identity function | 19.4 | 19.4 | 19.4 | 66.1 | 66.1 | 66.1 | 85.2 | 85.2 | 85.2 |
| 3DConv | 49.7 | 52.3 | 53.1 | 95.7 | 95.7 | 95.8 | 99.2 | 99.3 | 99.3 |
| DeciWatch | 76.6 | 76.7 | 68.1 | 94.4 | 94.3 | 87.3 | 99.2 | 99.2 | 96.1 |
| bi-ConvLSTM - Model S | 37.8 | 34.9 | 39.0 | 91.8 | 92.1 | 92.2 | 99.4 | 99.7 | 99.2 |
| bi-ConvLSTM - Model C | 35.9 | 39.0 | 38.5 | 93.1 | 93.6 | 92.6 | 99.8 | 99.7 | 99.7 |

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| 3DConv | 46.5 | 51.6 | 47.3 | 95.5 | 95.5 | 95.8 | 99.2 | 99.3 | 99.2 |
| DeciWatch | 76.0 | 75.9 | 36.8 | 94.2 | 94.2 | 74.9 | 99.2 | 99.2 | 92.8 |
| bi-ConvLSTM - Model S | 38.8 | 37.4 | 35.9 | 92.7 | 92.1 | 91.2 | 99.4 | 99.5 | 99.3 |
| bi-ConvLSTM - Model C | 39.2 | 39.5 | 37.1 | 92.5 | 92.9 | 92.6 | 99.6 | 99.3 | 99.6 |

Test results

Decreased frame rate:

- ▶ 3DConv: benefit
- ▶ DeciWatch: drawback
- ▶ bi-ConvLSTM: benefit for less noise

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Test results

bi-ConvLSTM: Model S vs Model C:

- ▶ Not as a big of a concern

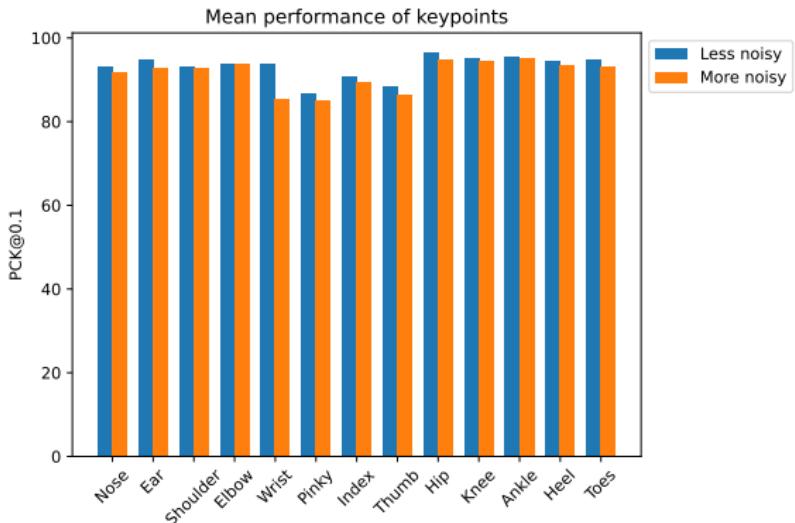
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Test results

Worst performing keypoints:

- ▶ Pinkies, index fingers and thumbs
- ▶ Not included during pretraining (minor effect - heels and toes)
- ▶ A lot of movement



Discussion

Which model is the best?

- ▶ Greatest testing accuracy: DeciWatch 1.1/1.2
- ▶ Greatest rough estimation: bi-ConvLSTM Model C 1.1
- ▶ Speed and memory: 3DConv

General reflections

Mistakes we have made

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 - ▶ Should have estimated parameters of data

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- ▶ Finetuning

- ▶ Groundtruth outside of bbox



Future work

1. DeciWatch with all frames

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2. DeciWatch with vision transformer

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3. Avoid overfitting

Future work

1. DeciWatch with all frames
2. DeciWatch with vision transformer
3. Avoid overfitting
4. Multiple retraining

Conclusion

Successfully developed and tested models that incorporate temporal smoothing pose estimation.

Extras: Mistakes Were Made!

Misimplemented evaluation-function

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4. bi-ConvLSTM: Model C is now always better than Model S

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| bi-ConvLSTM - Model C | 31.5 | 32.2 | 30.8 | 71.8 | 72.0 | 71.9 | 86.4 | 86.4 | 86.5 |

Extras: Mistakes Were Made!

Misimplemented evaluation-function

1. Generally, same patterns
2. Decreased accuracies
3. Models do not improve the rough estimates
4. bi-ConvLSTM: Model C is now always better than Model S
5. 3DConv is generally the best model

| Accuracy metric | PCK@0.05 | | | PCK@0.1 | | | PCK@0.2 | | |
|-----------------------|----------|------|------|---------|------|------|---------|------|------|
| | 1.1 | 1.2 | 1.3 | 1.1 | 1.2 | 1.3 | 1.1 | 1.2 | 1.3 |
| Identity function | 19.4 | 19.4 | 19.4 | 66.1 | 66.1 | 66.1 | 85.2 | 85.2 | 85.2 |
| 3DConv | 33.3 | 33.4 | 32.8 | 72.5 | 72.4 | 73.1 | 85.8 | 85.8 | 86.0 |
| DeciWatch | 32.8 | 33.8 | 30.9 | 68.0 | 68.1 | 62.7 | 85.1 | 84.9 | 82.8 |
| bi-ConvLSTM - Model S | 31.7 | 30.1 | 31.6 | 71.5 | 68.3 | 71.3 | 86.3 | 82.5 | 86.2 |
| bi-ConvLSTM - Model C | 32.0 | 32.2 | 31.8 | 72.2 | 72.2 | 71.4 | 86.6 | 86.5 | 86.5 |

| Accuracy metric | PCK@0.05 | | | PCK@0.1 | | | PCK@0.2 | | |
|-----------------------|----------|------|------|---------|------|------|---------|------|------|
| | 2.1 | 2.2 | 2.3 | 2.1 | 2.2 | 2.3 | 2.1 | 2.2 | 2.3 |
| Identity function | 19.4 | 19.4 | 19.4 | 66.1 | 66.1 | 66.1 | 85.2 | 85.2 | 85.2 |
| 3DConv | 33.1 | 33.3 | 32.7 | 72.1 | 72.3 | 72.6 | 85.6 | 85.7 | 85.6 |
| DeciWatch | 21.3 | 26.4 | 19.4 | 51.1 | 58.7 | 48.1 | 77.1 | 81.0 | 77.0 |
| bi-ConvLSTM - Model S | 30.9 | 31.6 | 30.6 | 71.2 | 71.6 | 70.7 | 86.0 | 86.1 | 86.2 |
| bi-ConvLSTM - Model C | 31.5 | 32.2 | 30.8 | 71.8 | 72.0 | 71.9 | 86.4 | 86.4 | 86.5 |