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Denoising of event-based sensors with deep neural networks

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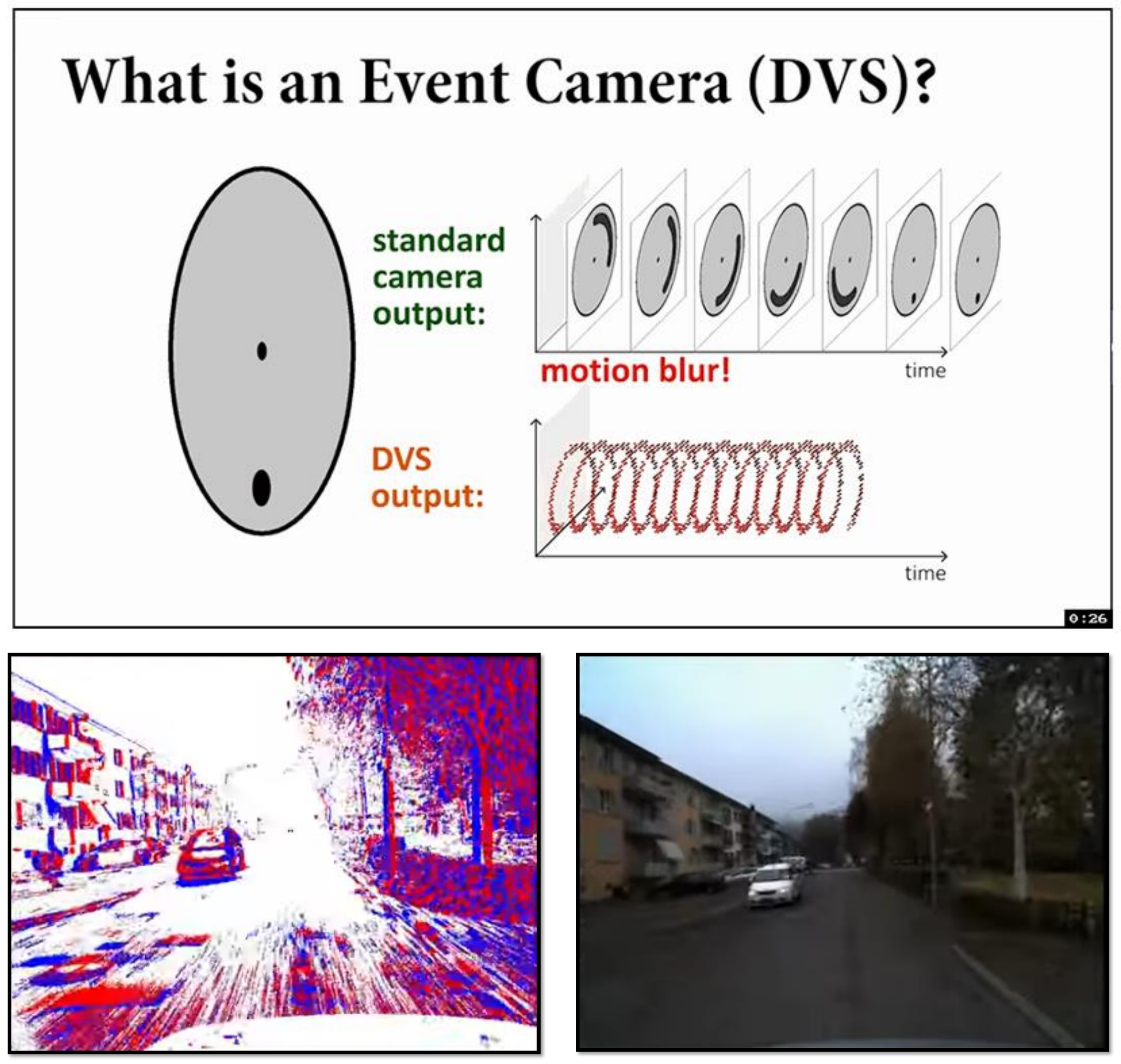
ABSTRACT

We propose two learning-based methods for the denoising of event-based sensor measurements:

- **ConvDAE** : convolutional denoising auto-encoder
  - Based on the convolutional neural network (CNN)
  - Compatible with existing image-based deep denoisers and high-level vision tasks
- **SeqRNN**: sequence-fragment recurrent neural network
  - Based on the recurrent neural network (RNN)
  - Realize online denoising while keeping the event's original AER representation.

INTRODUCTION



event camera   standard camera

Fig. 1 The working mechanism of the event camera and its comparison with standard frame-based cameras.

- **A novel neuromorphic imaging sensor**
- **Responses only to brightness changes asynchronously**
- **The output is a stream of events containing positions, time, and polarities (±1)**
- **Features: low power consumption, low latency, HDR, but noisy**

METHODS

ConvDAE: convolutional denoising auto-encoder

The basic structure of ConvDAE is a simplified U-Net, with only one convolutional layer in each encoding or decoding layer. Dropout layer corrupted original images and nearest neighbor filter pre-denoised reference images serve as input and "ground truth" respectively.

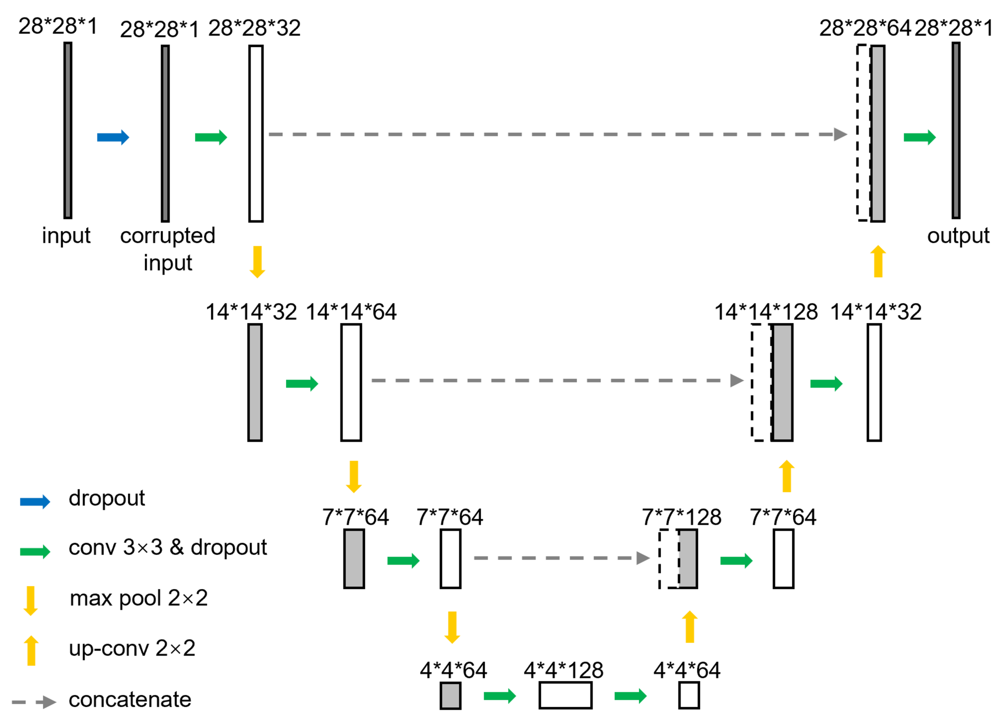


Fig. 2 The architecture of the proposed self-supervised convolutional denoising auto-encoder (ConvDAE).

The event sequence is mapped into a series of video frames before denoising

SeqRNN: sequence-fragment recurrent neural network

The first part consists of two LSTM layers, and the second part is composed of three fully connected layers and a softmax layer. Original event segments and nearest neighbor filter pre-denoised reference event segments serve as input and "ground truth" respectively.

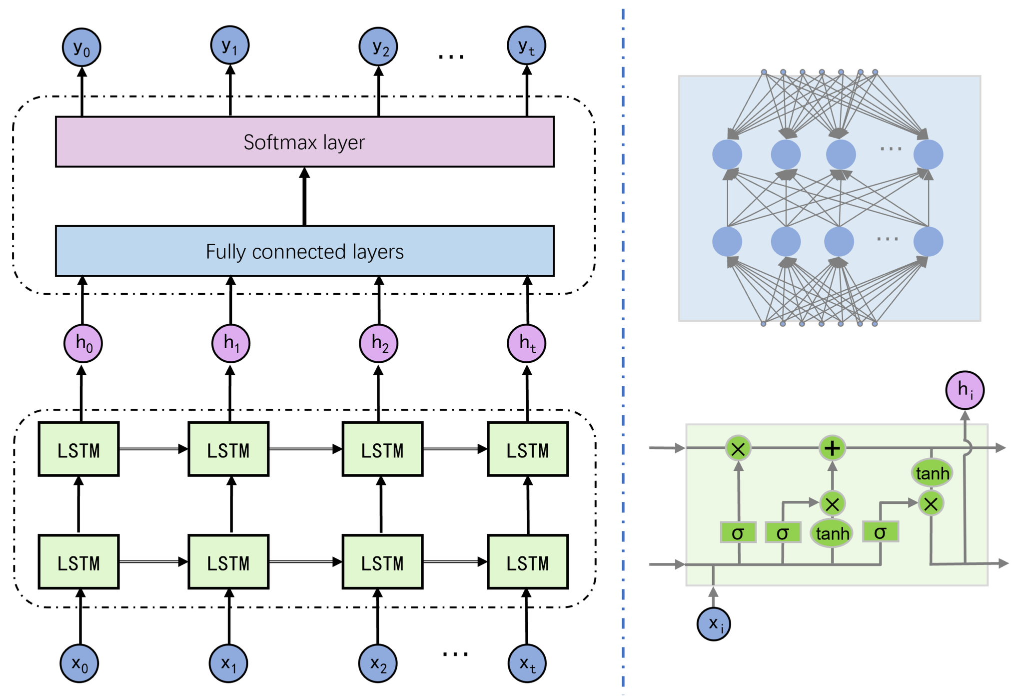


Fig. 3 The architecture of the proposed sequence-fragment recurrent neural network (SeqRNN).

RESULTS

we demonstrate the effectiveness of proposed ConvDAE and SeqRNN with N-MNIST dataset, which is collected by capturing static images in classical computer vision dataset MNIST with a moving event camera.

Original: images mapped from original event sequences;
Reference: reference images mapped from the pre-denoised event sequences via nearest neighbor filtering (NNF).

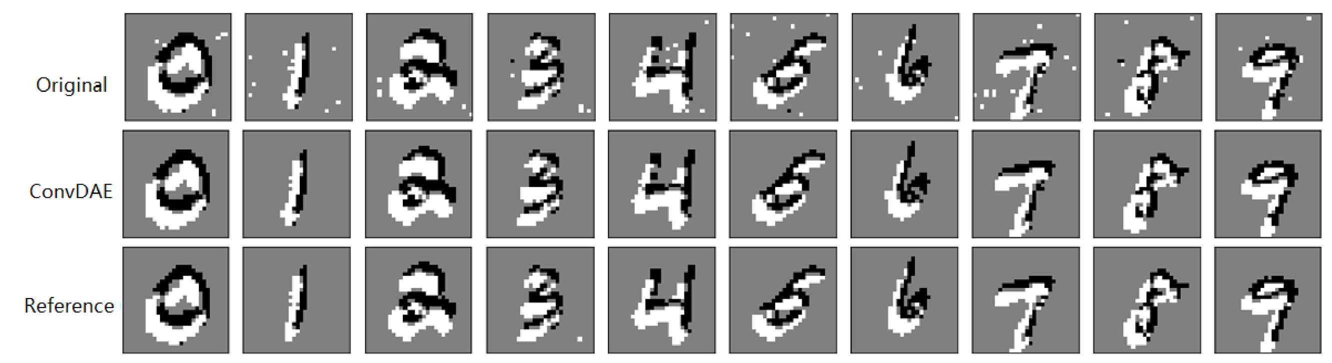


Fig. 4 The denoising results of ConvDAE.

ConvDAE efficiently removes the dispersed noise and performs better in distinguishing the signal and noise especially around the objects compared with NNF pre-denoised reference images.

Fig. 4 The denoising results of SeqRNN.

The noise shown in the original event segments can be filtered out clearly by SeqRNN, which meanwhile outperforms the NNF algorithm in some details.

CONCLUSIONS

We come up with two learning-based methods named **ConvDAE** and **SeqRNN** for the denoising of event camera data, and demonstrate their effectiveness and flexibility with real data experiments.

As light-weight denoisers, CNN-based ConvDAE and RNN-based SeqRNN can be easily adapted to image-based and event-based downstream tasks' solutions, respectively

In the future, we will test the proposed methods on more complicated datasets, and evaluate their denoising performance based on their assistance for the downstream high-level vision tasks.

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