Particle tracking with multiple event cameras

VISION

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November 15, 2022

Introduction

How can particles in a wind tunnel be tracked in 3D using a set of cameras?

- An event based camera is well suited for this application.
- In order to estimate the motion an individual particle, the output data must be processed by the Kalman filter.

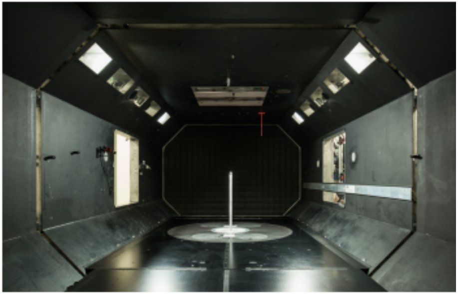


Figure 1: Wind Tunnel

What are event-based cameras?

- An event based camera is a camera which can detect a change in intensity for individual pixels.
- Individual pixel intensities are continuously compared to a reference intensity value. If the difference in intensity exceeds a pre-defined threshold an event is registered.
- Such an event is defined by the time of the pixel intensity change, its position and whether the change increases or decreases the pixel intensity.

Figure 2: Differences between regular and event cameras.

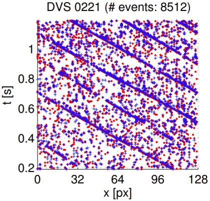
What are the properties of event-based cameras?

Event-based cameras differ from regular frame cameras:

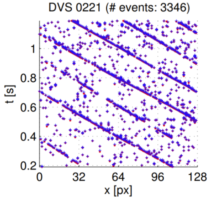
- They have a much higher dynamic range ($\sim 120dB$) than the regular frame camera. The dynamic range of the human eye is $\sim 30dB$.
- The temporal resolution is much higher, *i.e.* in the μs range. Pixels in event-based cameras are independent from each other. The fact the temporal resolution is high reduces the motion blur.
- Perfect for embedded systems. Low power consumption.

Figure 3: Differences between regular and event cameras.

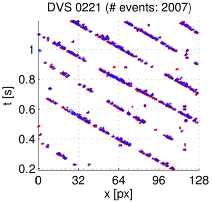
How can we pre-process the recordings?



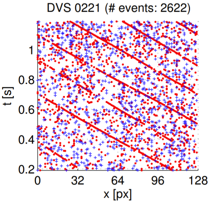
(a) No filter.



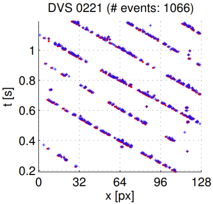
(b) Pair filter.



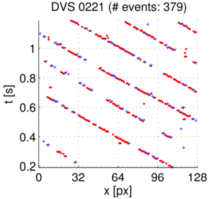
(c) Neighbour filter.



(d) Suppression filter.



(e) Pair & neighbour filters.



(f) All filters.

Figure 4: Pre-processing of the recordings using filters.

Which type of tracker is appropriated to track a particle?

Tracking a particle over time means to find the events corresponding to the particle and link them in order to reconstruct the trajectory.

Stochastic trackers are used to estimate a set of state variables (*e.g.* position, velocity) continuously. The estimation is performed based on a set of measurements (*i.e.* events) and the expected noise.

The most commonly used type of stochastic tracker is the **Kalman filter**, which is well suited to process data from event-based cameras. The Kalman filter assumes there is an uncertainty in the state variables and the measurements. The following assumptions are made:

- the system is linear;
- the noise and the uncertainty about the estimate of the system are Gaussian.

How the Kalman filter is used to track a particle?

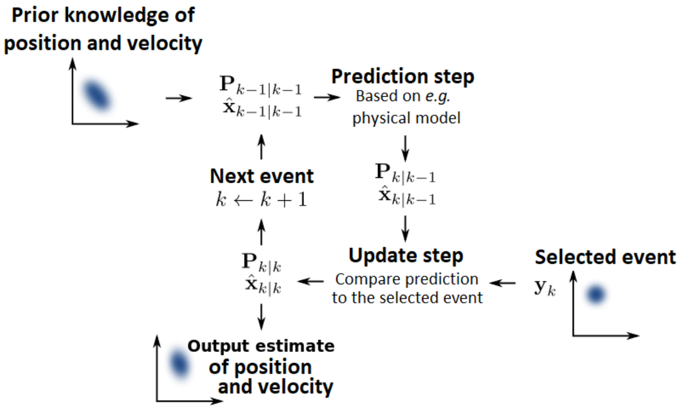


Figure 5: **The Kalman filter.** $\hat{x}_{k|k-1}$ denotes the estimate of the position and velocity at event number k before the k-th selected event y_k has been taken into account. $P_{k|k-1}$ is the corresponding uncertainty. Original illustration found on wikipedia.

How to determine which event add to which track?

The simplest strategy to select the event that corresponds to the particle we want to track is to use the gating method.

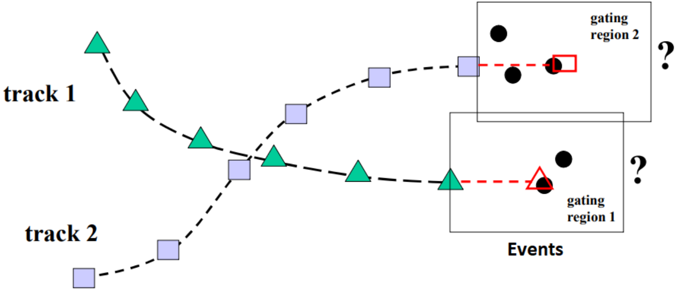


Figure 6: **The gating method.** Original illustration found in the slides a course of Robert T. Collins, associate professor at Penn State University.

More sophisticated strategies exist like the Multiple Hypothesis Tracking method, which is however much more computationally expensive.

How to reconstruct the track in the 3D space?

There exist two strategies for reconstructing the 3D track of a particle [1]:

1. tracking the particle in the 2D sensor space of each camera and merging the 2D tracks into the respective 3D track;
2. directly relating the events to the 3D space using the projection equation and performing the tracking in the 3D space.

How to reconstruct the track in the 3D space?

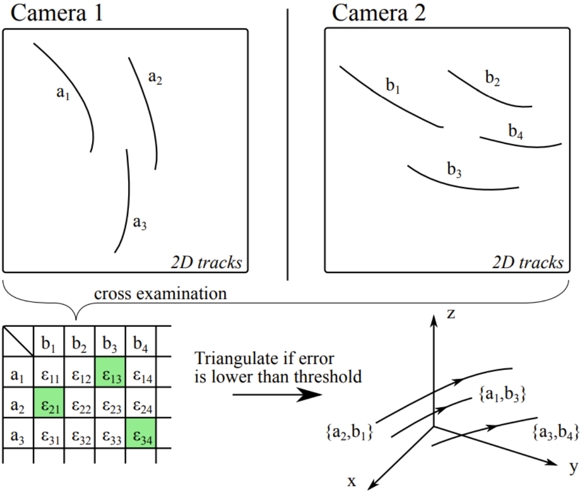


Figure 7: **The first strategy [1].** A possible match is given if the epipolar error between two tracks is lower than a given threshold; the two tracks are then triangulated to calculate the 3D track.

How to reconstruct the track in the 3D space?

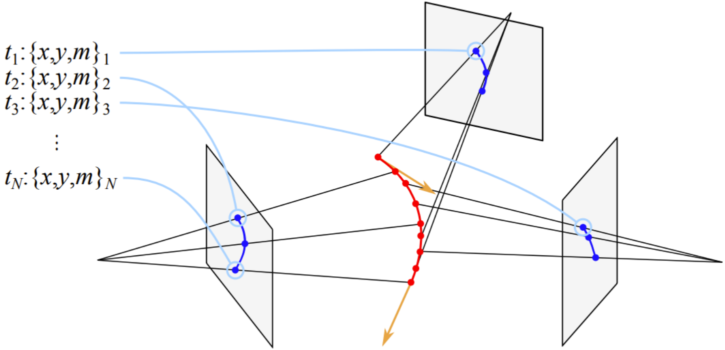


Figure 8: **The second strategy [1].** The sequence of events is ordered in time and for each event the matrix of the respective camera m is used to relate the event and then to perform the tracking in the 3D space.

Thank you!

Bibliography

Borer, David J., "4d flow visualization with dynamic vision sensors," Ph.D. dissertation, 2014. [Online]. Available: http://hdl.handle.net/20.500.11850/95489