Motion Compensation

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Final Presentation

Outline

- **Introduction**
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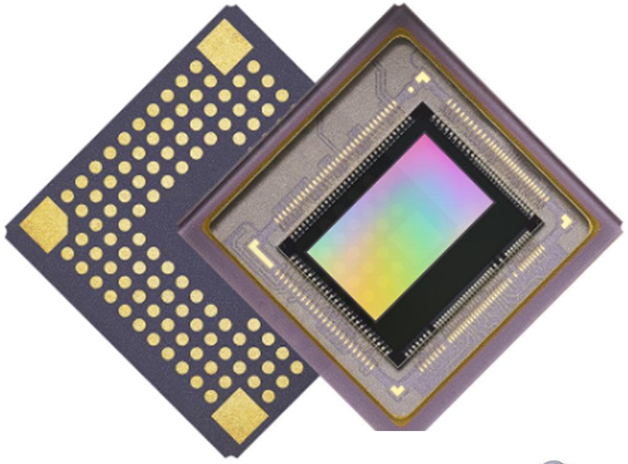
  - Motion Compensation
- **Motion Compensation**
  - With Known Plane
  - Without Prior Knowledge of Plane & Velocity
- **Industrial application : Barcode Reconstruction**
  - Using Constant Threshold
  - Detecting Peaks
  - Applying Probabilistic Model
  - Generating Image Luminance
- **Future Work**

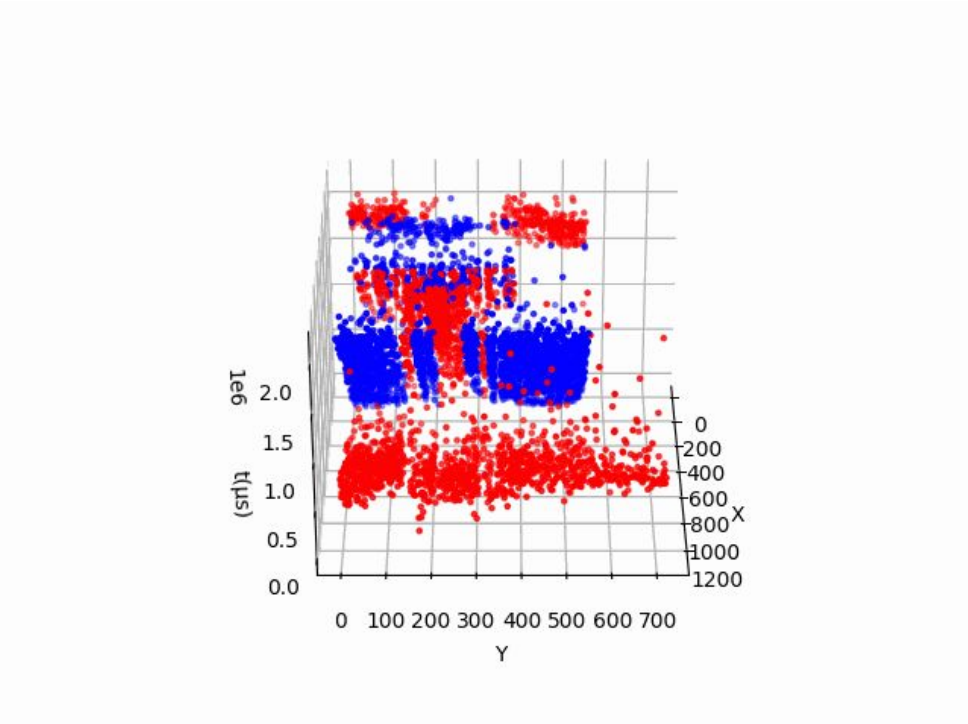
Introduction

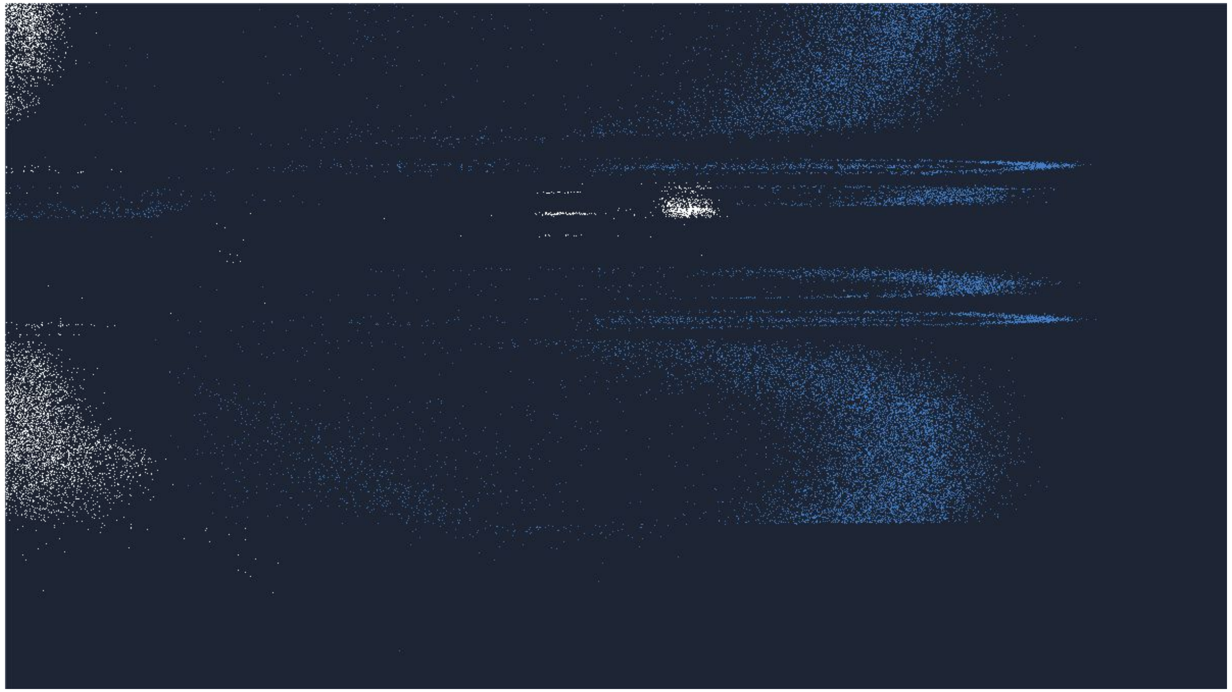
Event-cameras advantages :

- Ultra-high time resolution (µs)
- High dynamic range
- Low power consumption



Introduction





Given the high temporal resolution of the event-based camera data, how can we compensate for the lower spatial resolution?

Motion Compensation

The idea is to synchronize the events by warping them to a common time reference, effectively aligning events generated by the same scene edge.

$$\mathbf{e}_k \triangleq (t_k, \mathbf{x}_k, p_k)$$

e_k is the triggered event at timestamp t_k.

$$\mathbf{x}'_k = \mathbf{x}_k - (t_k - T) \cdot \mathbf{v}(\mathbf{x}_k)$$

x_k, x'_k represent the pixel position (x, y), with x'_k being the warped position at the time reference T.

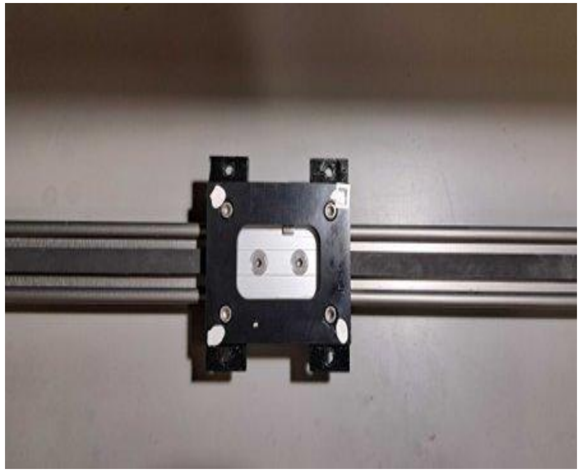
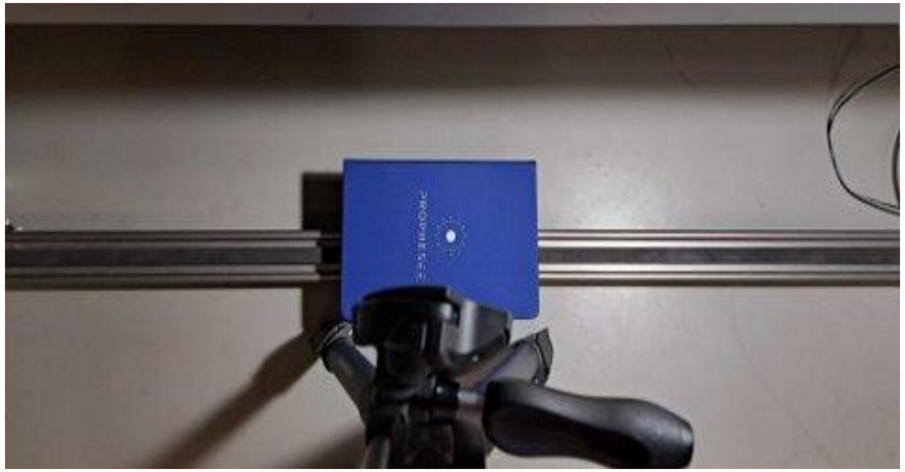
$v(x_k)$ is the affine velocity field.

$$I(x, T) = \sum_{e_k \in E} p_k \cdot \delta_{Dirac}(x - x'_k)$$

E is the set of all occurred events.

Motion compensation with known plane

Experimental setup

Assumption :

- **Motion:** Rectilinear and uniform
- **Camera Position:** Perpendicular to motion (notebook moves left to right)

Results

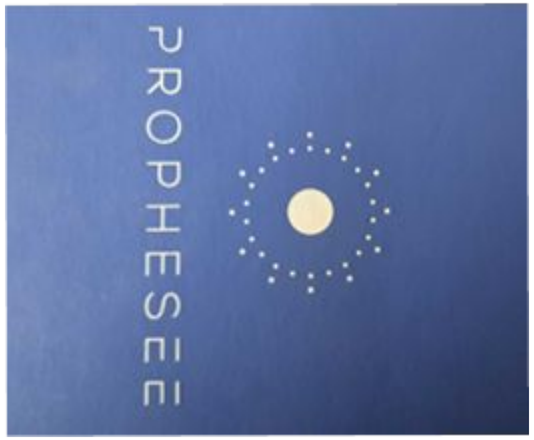
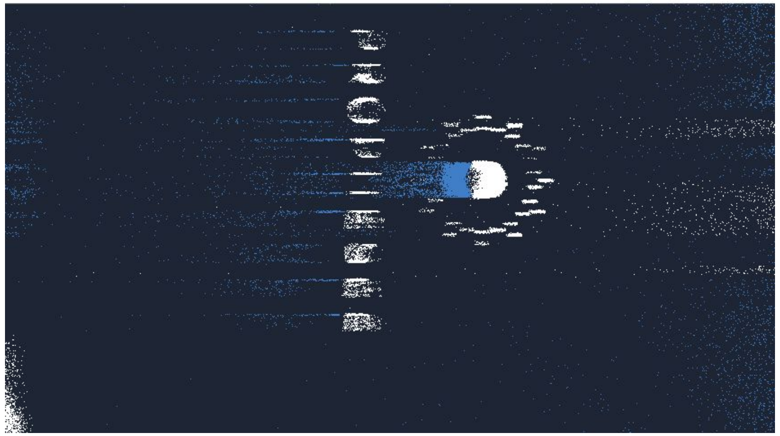


Image RGB du notebook

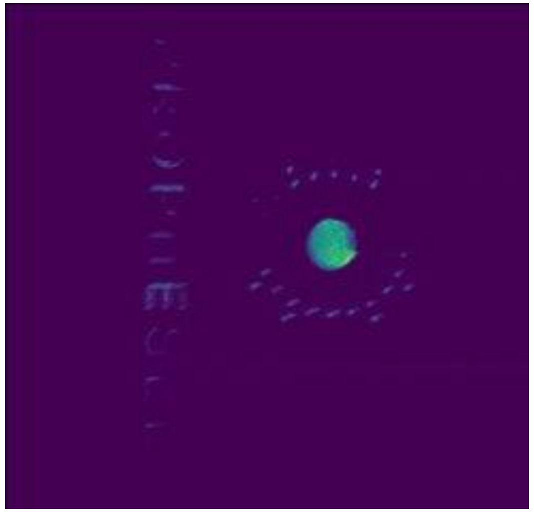


capture d’écran de données événementielles du notebook

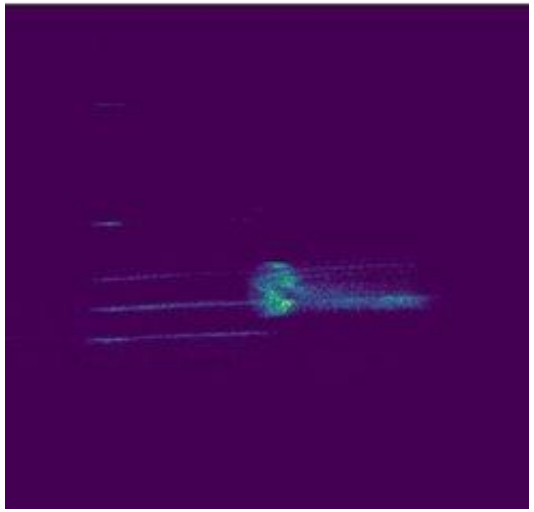
Résultat de l’histogram compensé

Compensated Histograms Relative to Conveyor Velocity

$v = 0.1\, m \cdot s^{-1}$



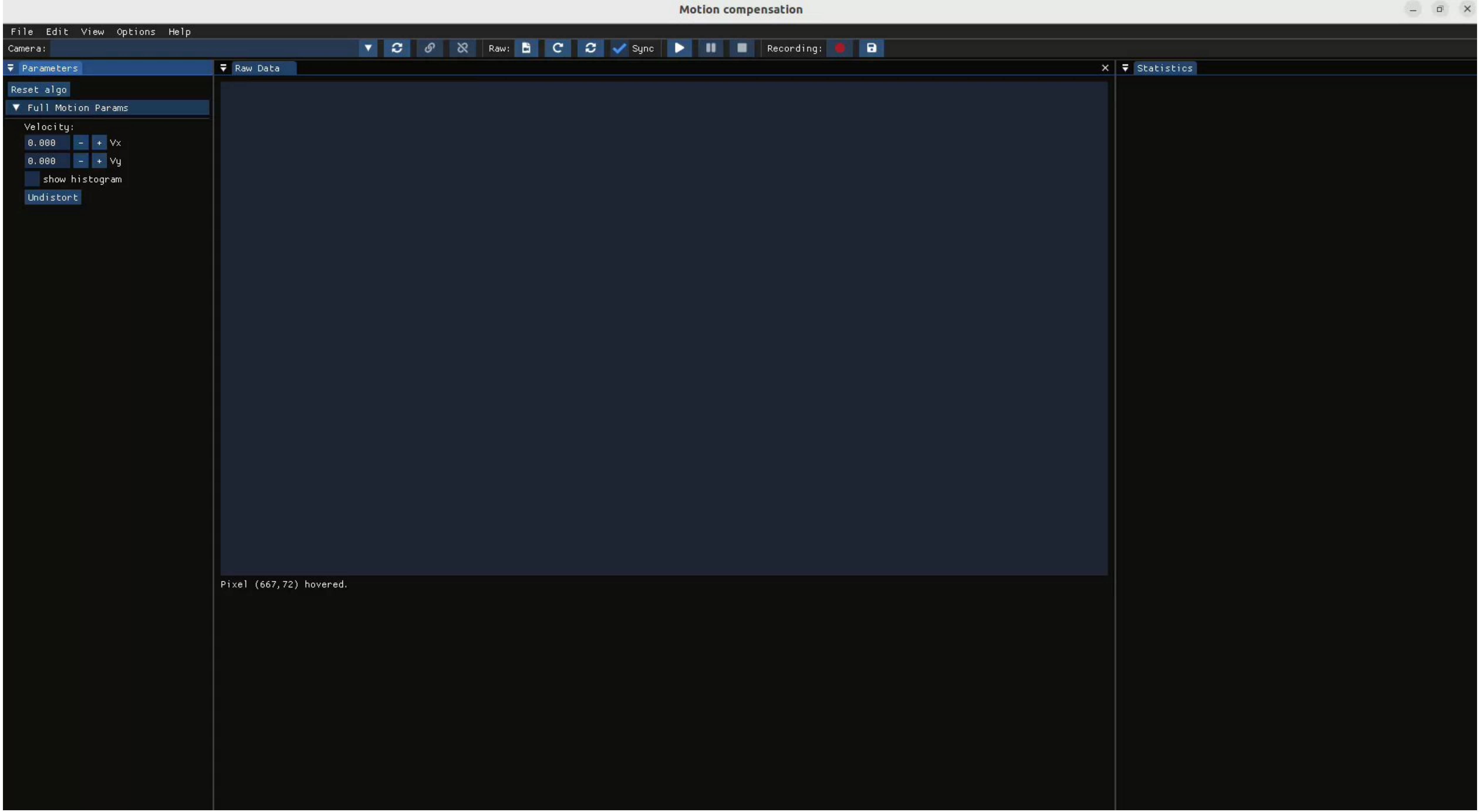
$v = 0.2\, m \cdot s^{-1}$



$v = 0.3\, m \cdot s^{-1}$

Limits :

- The accumulation time is fixed and cannot be adjusted.
- The initial recordings generated insufficient events.


Motion compensation
File Edit View Options Help
Camera:
Raw:
Sync
Recording:
Parameters
Raw Data
Statistics
Reset algo
Full Motion Params
Velocity:
0.000
Vx
0.000
Vy
show histogram
Undistort
Pixel (667,72) hovered.

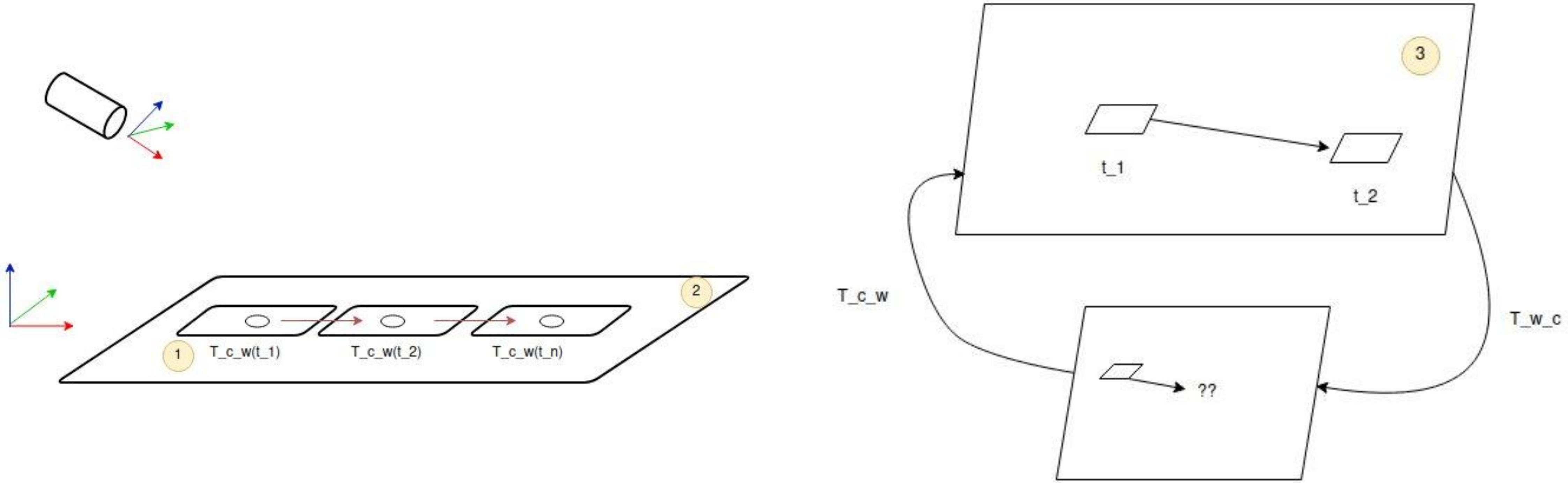
Motion Compensation: No Prior Knowledge of the Plane

Assumptions:

- The camera can be positioned at various angles and locations.
- The motion is straight-line and constant.

Experimental setup of this step

Methodology



1 Pose estimation

2 3D plane

3 Speed map per pixel

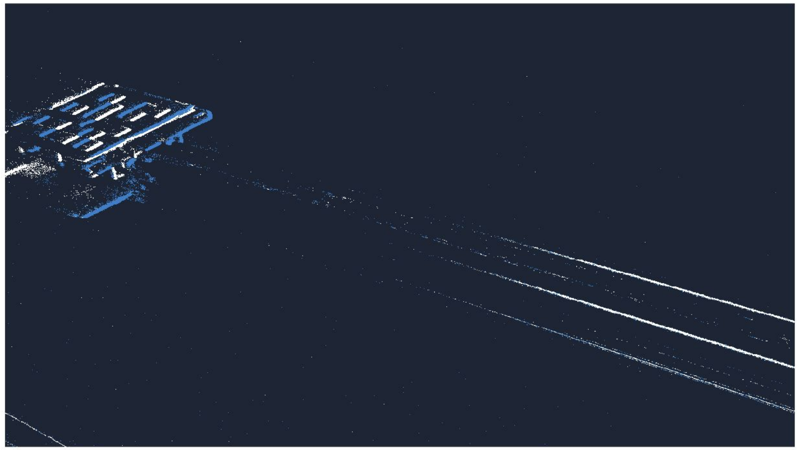
Methodology

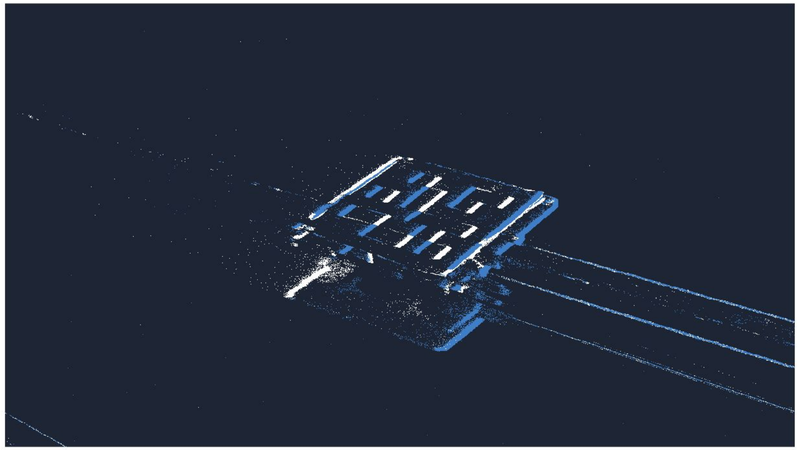
- **Plane Parameter Estimation:** Using least squares and SVD, the plane parameters are the eigenvector associated with the smallest eigenvalue in the SVD.

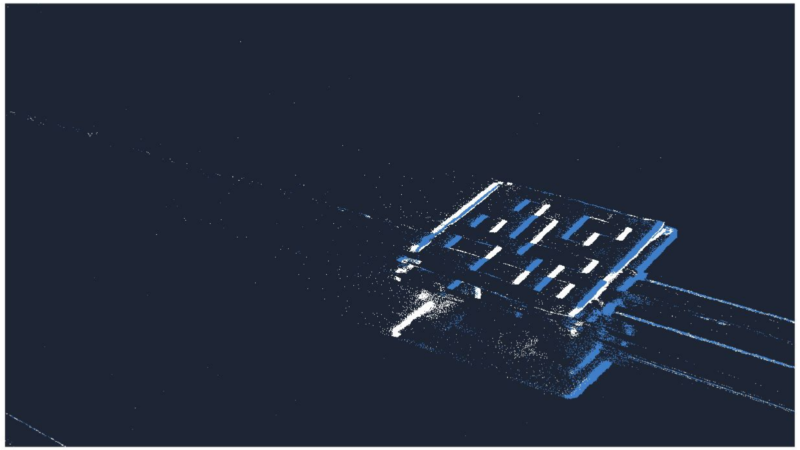
- **Average Velocity Calculation:** The average real-world velocity (V) is calculated from the displacement between the initial and final positions over a given time.

- **Speed Map Creation:** For each pixel, project its coordinates onto the estimated plane, assume it moves with velocity [V x delta_t] (fixed duration), and reproject the new position back into the camera scene.

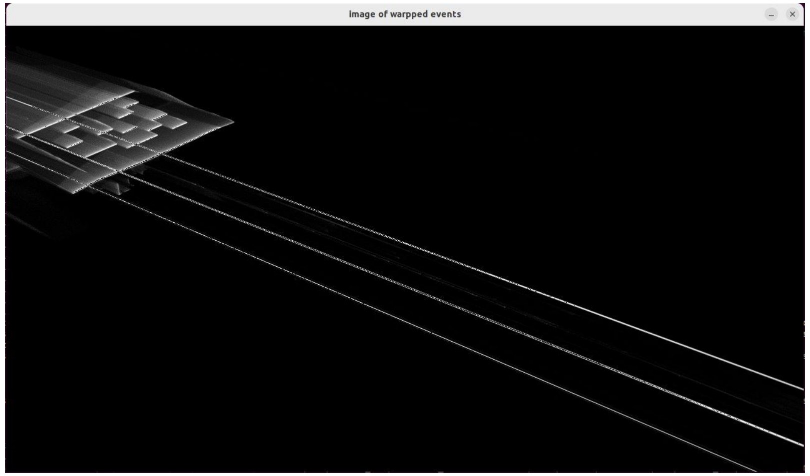
Data Visualization

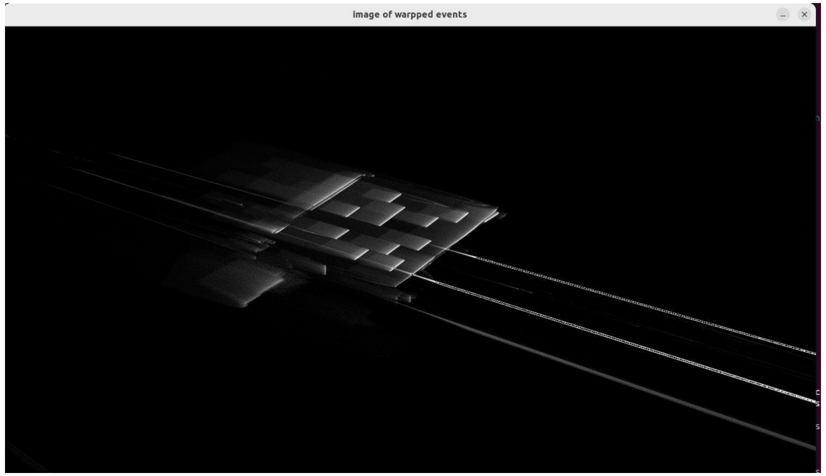


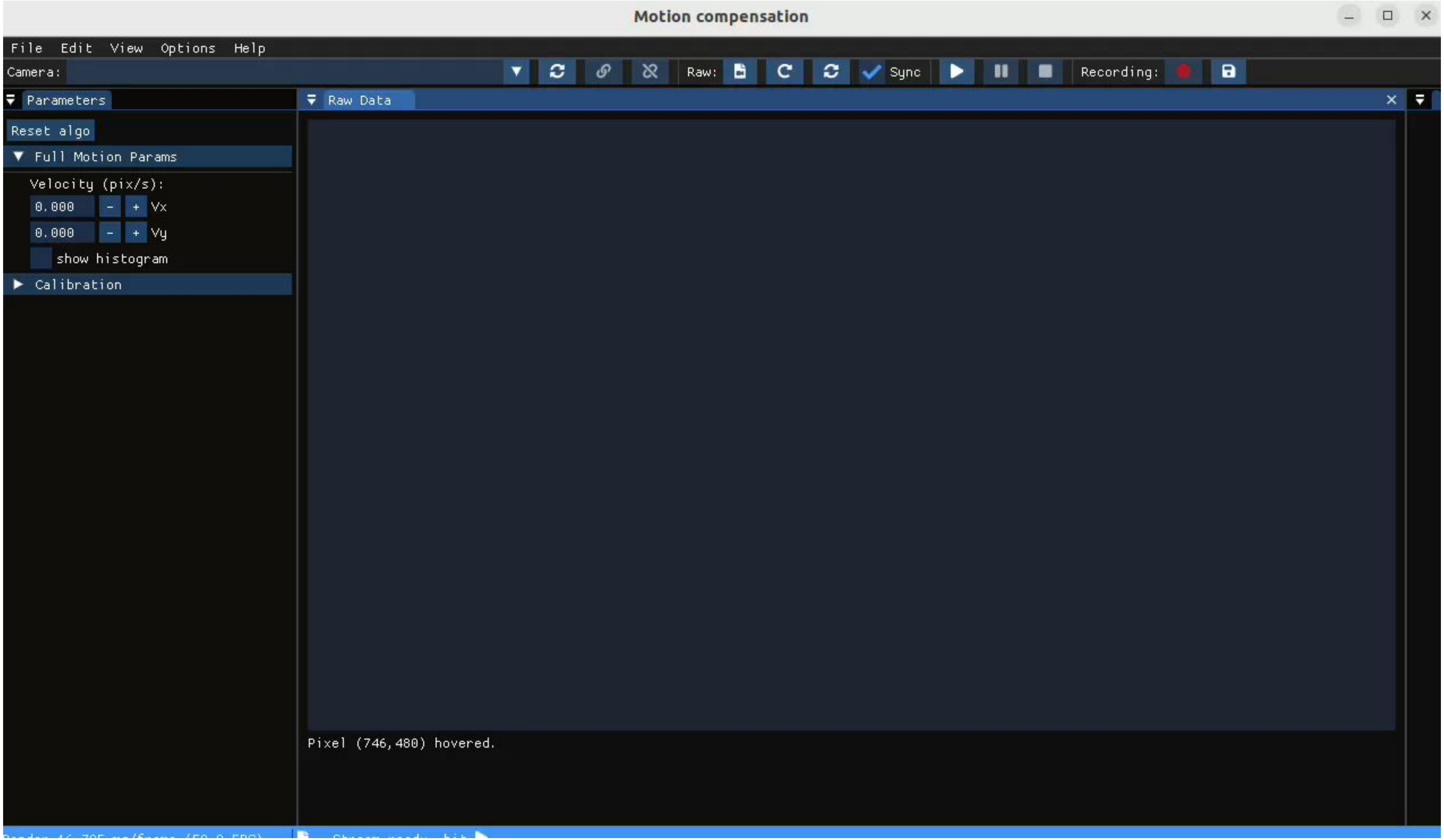




The output

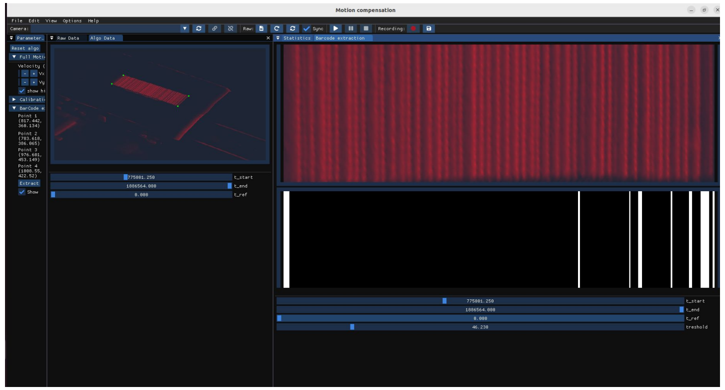


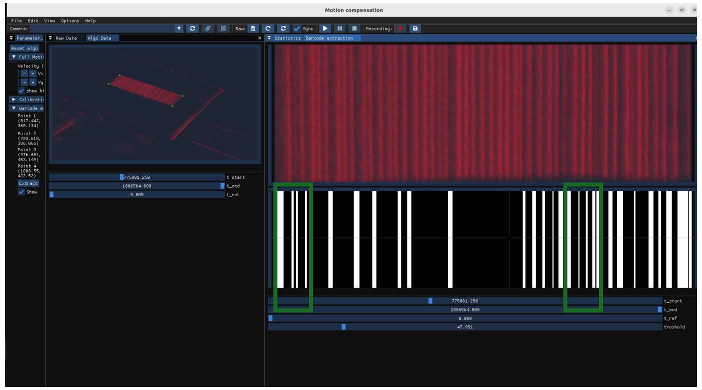


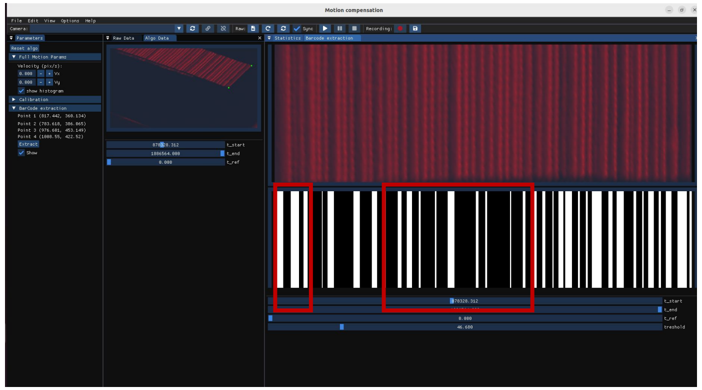

Motion compensation
File Edit View Options Help
Camera:
Raw:
Sync
Recording:
Parameters
Raw Data
Reset algo
Full Motion Params
Velocity (pix/s):
0.000
Vx
0.000
Vy
show histogram
Calibration
Pixel (746,480) hovered.

Industrial Application : barcode reconstruction

Approach 1 : constant threshold







The effect of varying the threshold on detecting the bars.

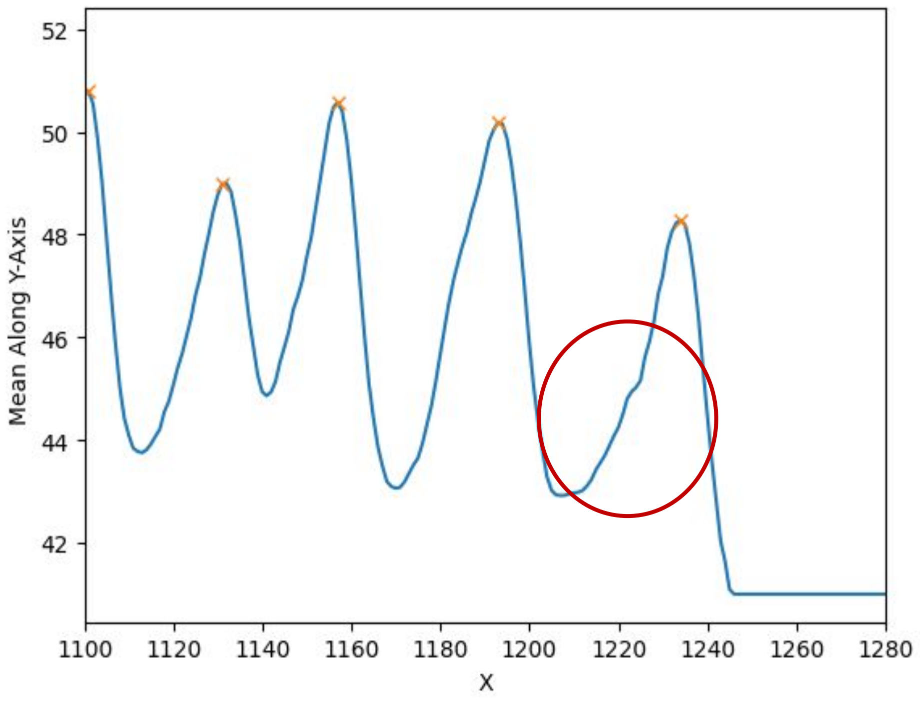
Interpretation and Limits

- Some well-placed bars are detected with a small threshold but are lost with a higher threshold, and vice versa.
- Accurate estimation of bar widths is essential for successful decoding.
- Working only with positive events may not capture sufficient contrast changes, as they only indicate transitions from darker to lighter regions.

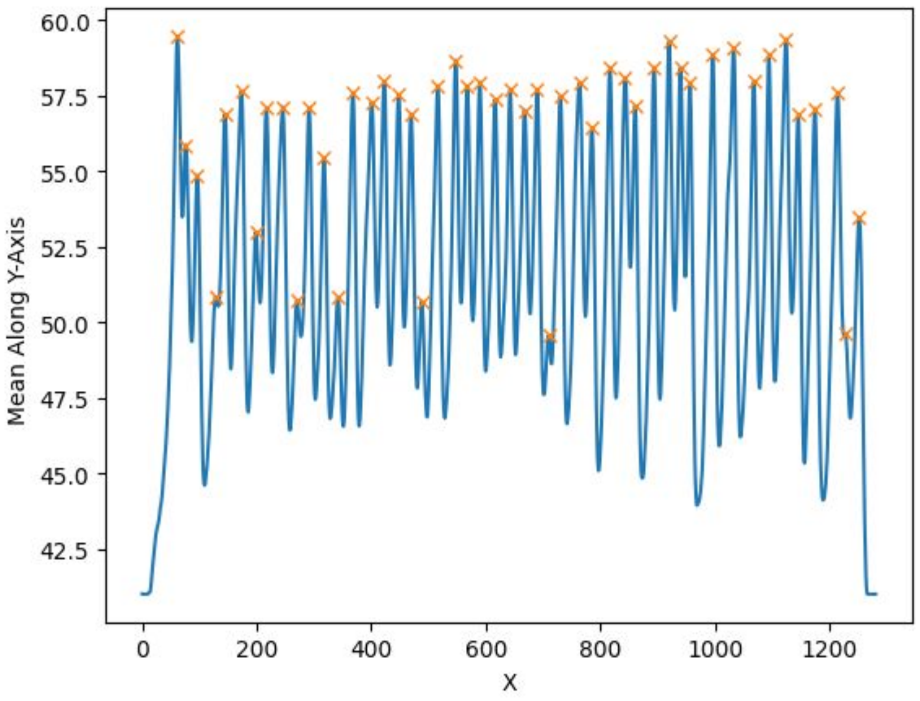
Approach 2 : Finding peaks

Sample 1: Recording with Conveyor Velocity Set to 0.3 m/s

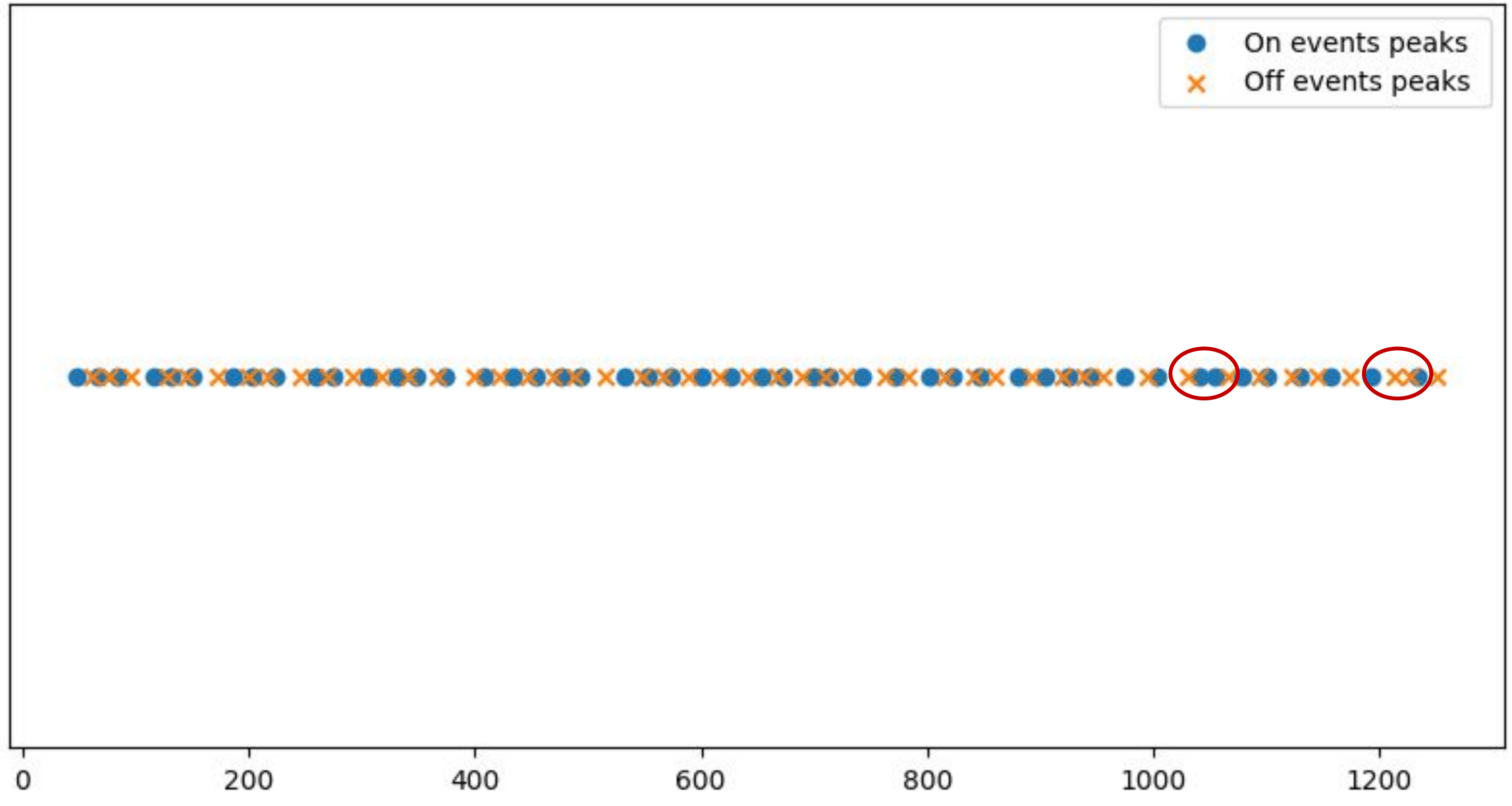
On events



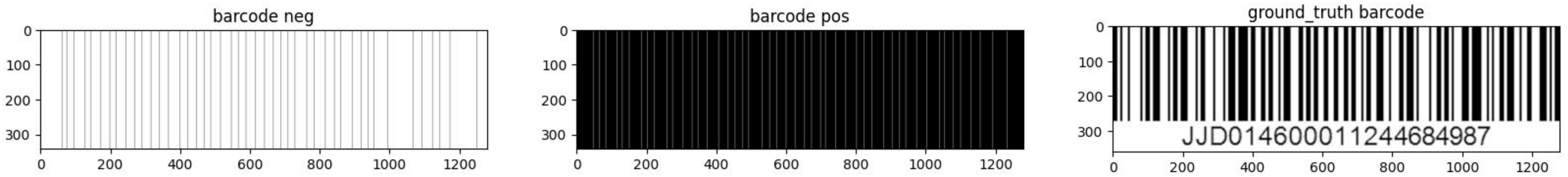
Off events



Verifying Alternating Peaks (positive-negative)



Drawing Edges for Each Peak

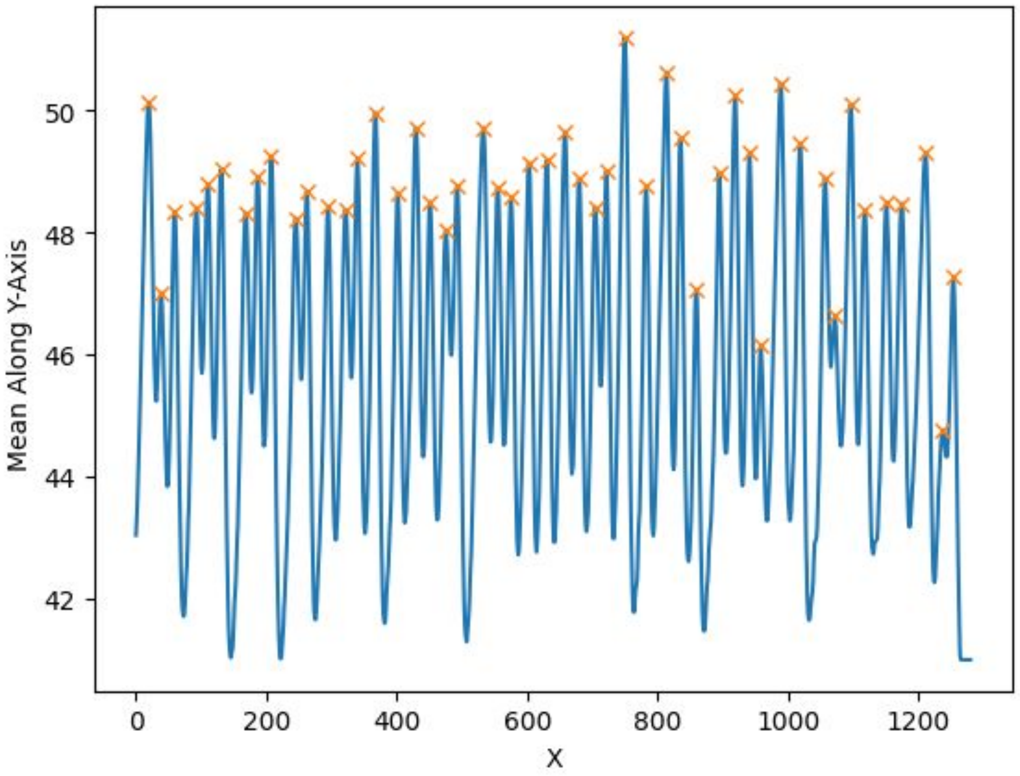


Reconstructing the bars

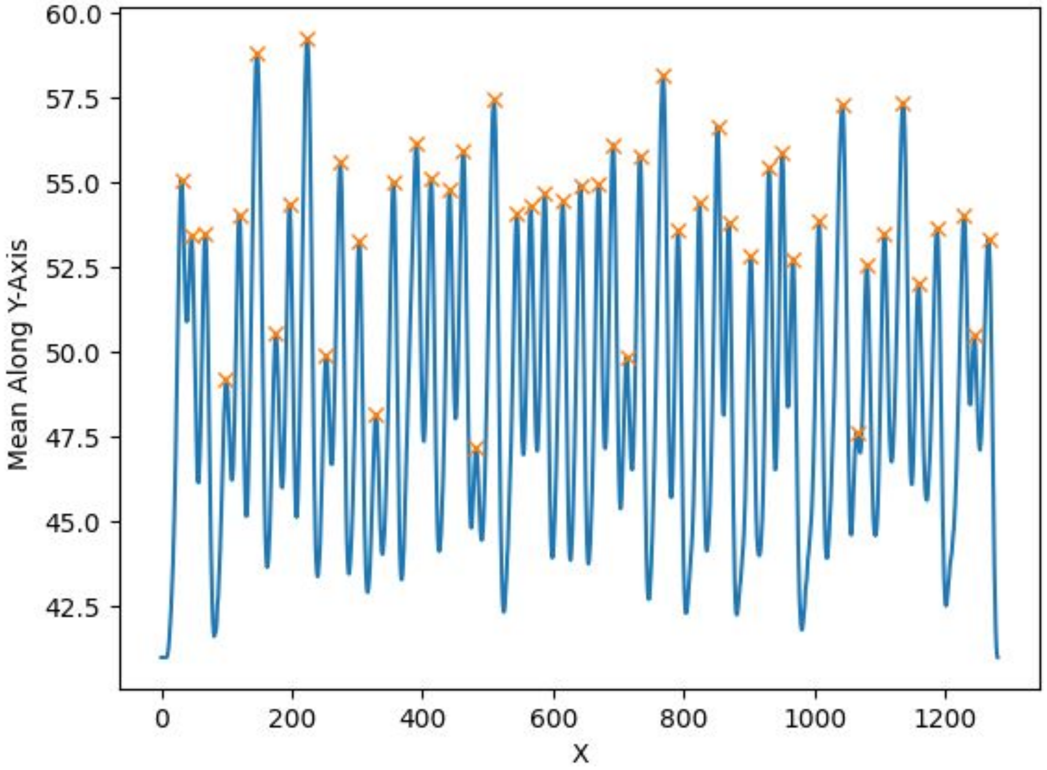
Second approach : Finding pe aks

Sample 1: Recording with Conveyor Velocity Set to 0.2 m/s

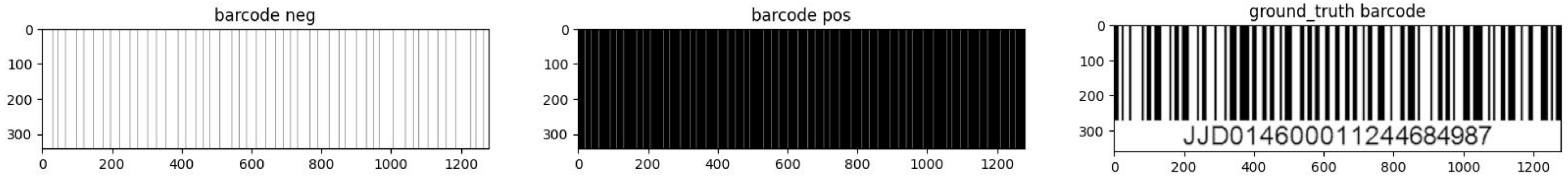
- On events



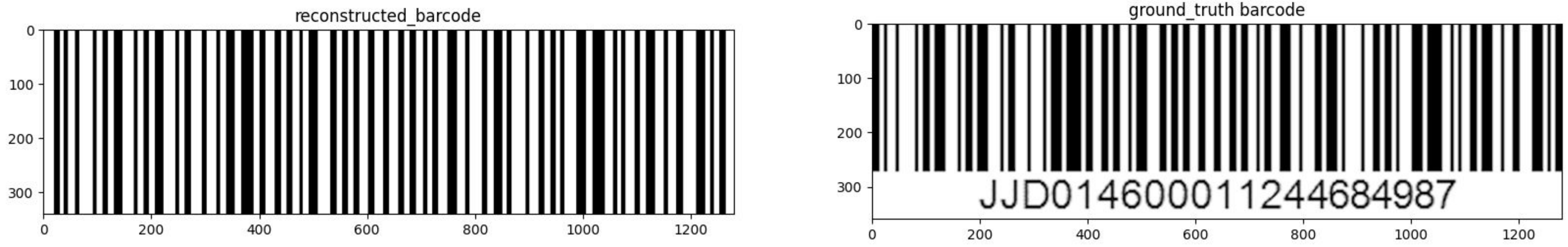
- Off events

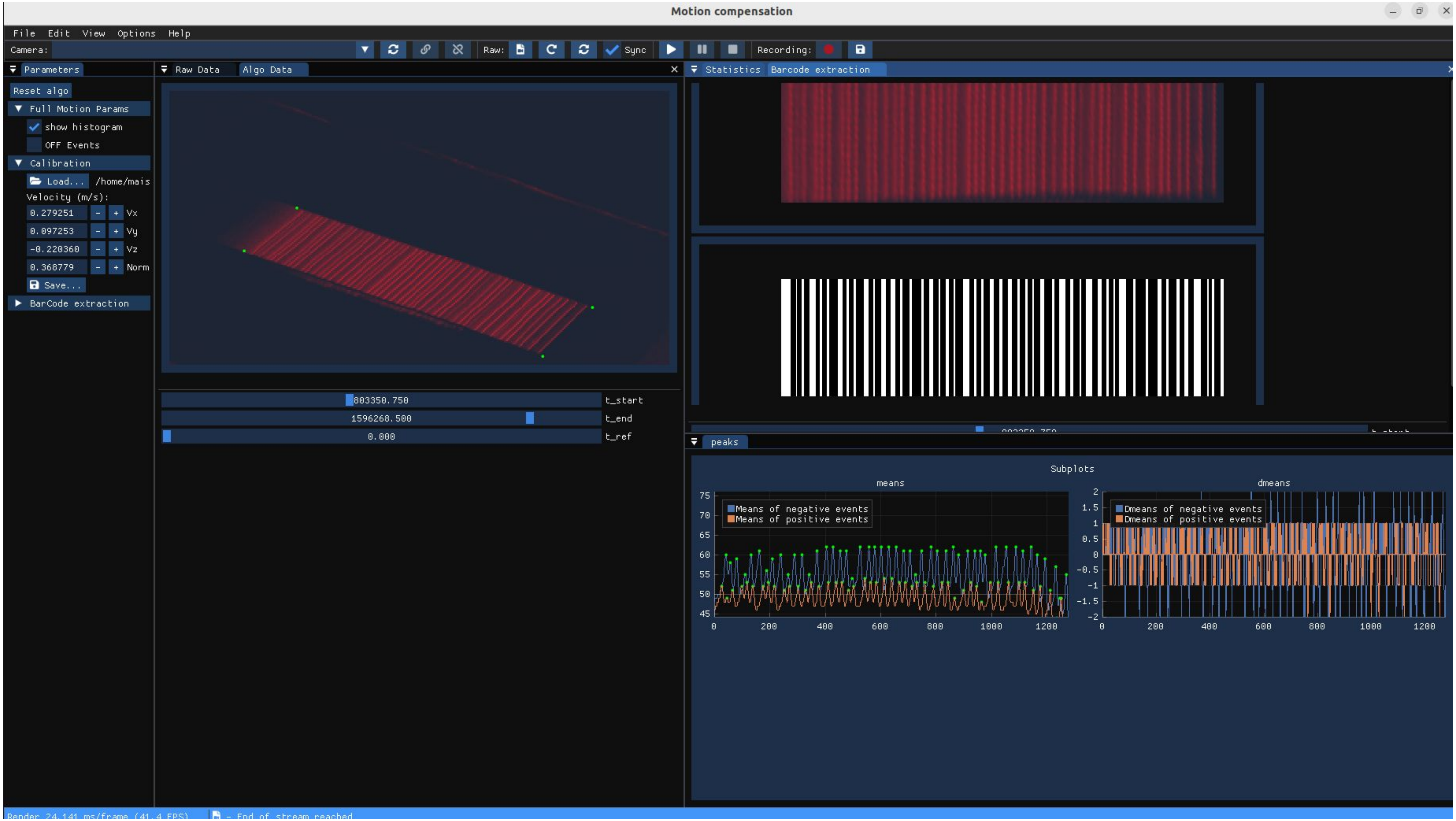


Drawing Edges for Each Peak



Reconstructing the bars





Motion compensation
File Edit View Options Help
Camera:
Raw:
Sync
Recording:
Parameters
Reset algo
Full Motion Params
show histogram
OFF Events
Calibration
Load... /home/mais
Velocity (m/s):
0.279251 Vx
0.097253 Vy
-0.220360 Vz
0.368779 Norm
Save...
BarCode extraction
Raw Data
Algo Data
803350.750 t_start
1596268.500 t_end
0.000 t_ref
Statistics
Barcode extraction
peaks
Subplots
means
Means of negative events
Means of positive events
dmeans
Dmeans of negative events
Dmeans of positive events
Render 24.141 ms/frame (41.4 FPS)
- End of stream reached

Interpretation and Limits

- Most bars and gaps appear to align visually with the ground truth (GT).
- The number of reconstructed bars matches the GT, excluding removed ones.
- A new recording at a conveyor velocity of 0.2 m/s showed significant improvement.
- All transitional edges (bar/gap or gap/bar) were accurately detected in the improved reconstruction.
- For Code 128 barcodes, sequences should consistently encode over 11 elementary modules, but this consistency is not seen in the reconstructed barcode.
- The bar widths fluctuate and lack a consistent pattern, unlike barcode symbology standards.

```
[72, 76, 77, 76, 80, 74, 79, 76, 74, 78, 77, 81, 78, 78, 77, 80, 27]
```

Sequences of 3 Bars and 3 Gaps in the Reconstructed Barcode

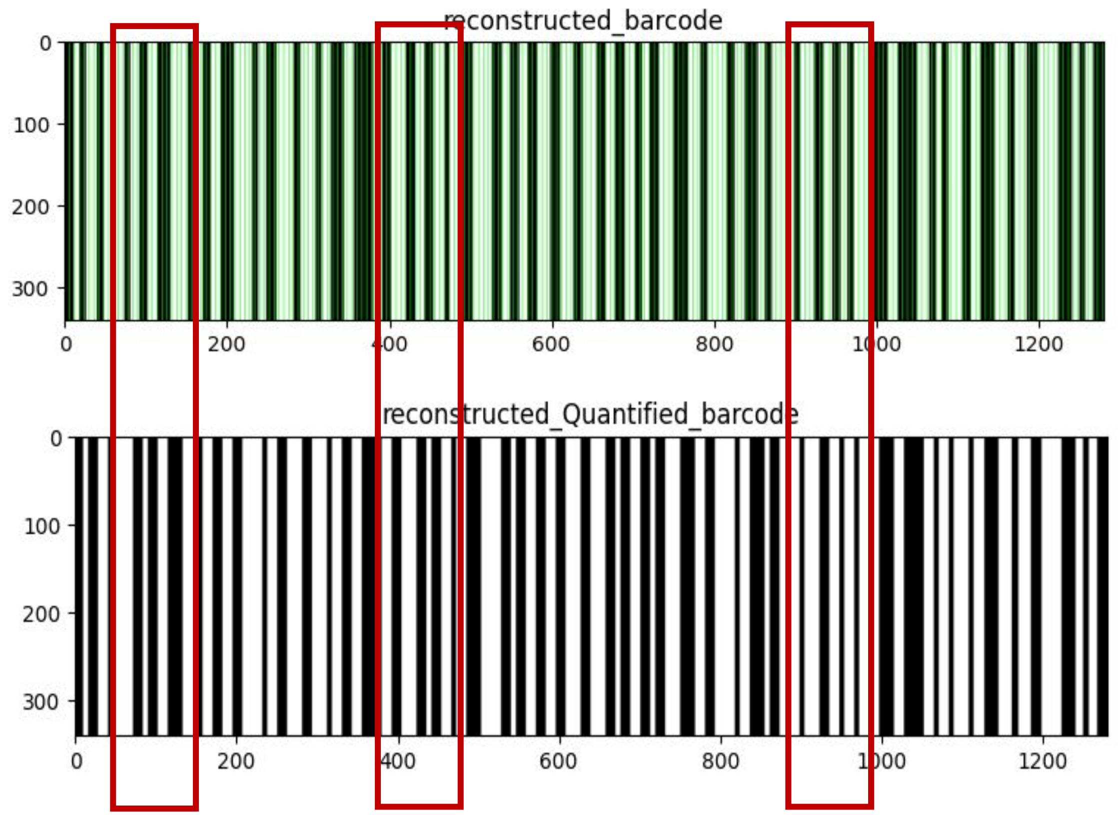
```
[80, 79, 79, 79, 79, 79, 79, 80, 79, 79, 79, 79, 79, 79, 79, 79, 14]
```

Sequences of 3 Bars and 3 Gaps in the ground truth Barcode

Approach 3: Quantifying the elementary width

- Barcodes are composed of a sequence of bars and spaces.
- For Code 128 symbology, each bar and space can range from 1 to 4 modules wide.
- The goal is to identify the elementary module width.
- Then, adjust the edge positions to accurately reconstruct the barcode.

Quantification Results for the Elementary Bar Width

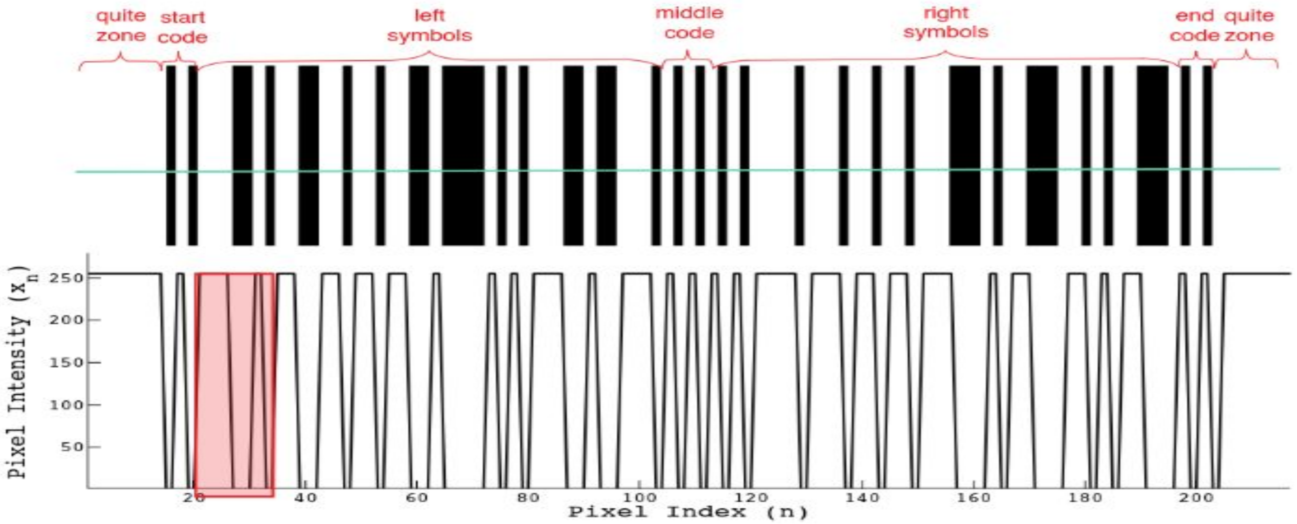


Limits :

- Some bars were adjusted to be thinner.
- Some bars were adjusted to be thicker.
- The closest symbol not necessarily the nearst edge in the quantified bars

Approach 4: Probabilistic Model for Estimating Complete Symbols

- **Objective:** Create a probabilistic model for code 128 barcodes.
- **Goal:** Decode symbols from a grayscale barcode image.
- **Method:** Use a dynamic Bayesian network.
- **Approach:** Apply a hierarchical Hidden Markov Model to handle barcode information.



A sample UPC-A barcode (top), its corresponding scanline (bottom), and a symbol in the scanline (shaded). [A unified probabilistic framework for robust decoding of linear barcodes]

Limits

- **Symbology Dependent:** The approach is specific to certain barcode symbologies and may not be generalizable.
- **Input Requirements:** It relies on grayscale images, while our case involves histograms of on and off events, which differ from grayscale data.
- Unfortunately, I couldn't implement this approach successfully due to time constraints and high computational costs.
- To address the limitations, it would be more relevant to convert the histograms of on and off edges into a grayscale image. This way, the existing approach, which relies on grayscale images, can be adapted to work with our data.

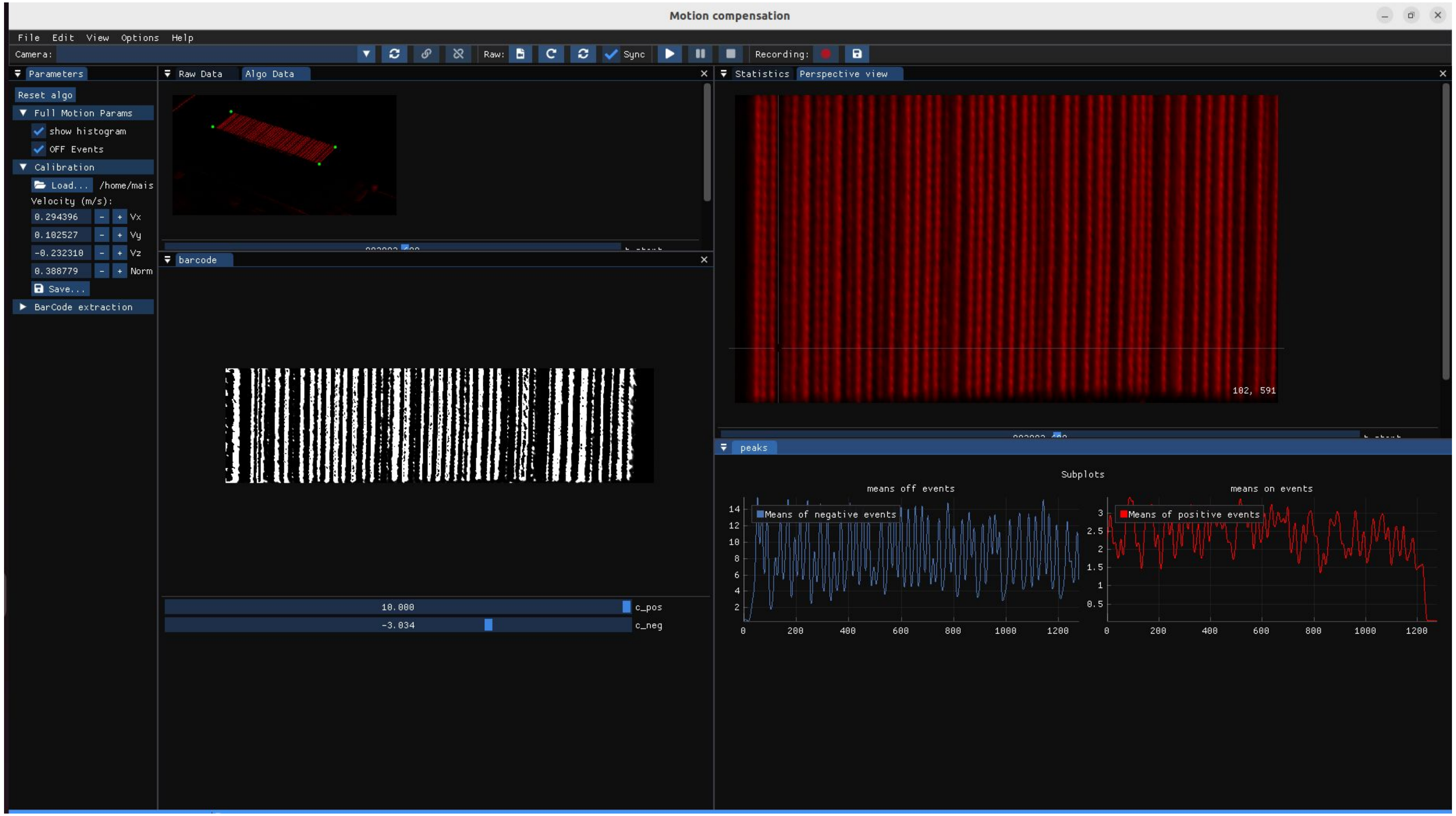
Approach 5 : Generating image luminance

- The intensity I of a pixel in an event-based camera is defined by the following equation from a source timestamp t_0 to to a target timestamp t_1:

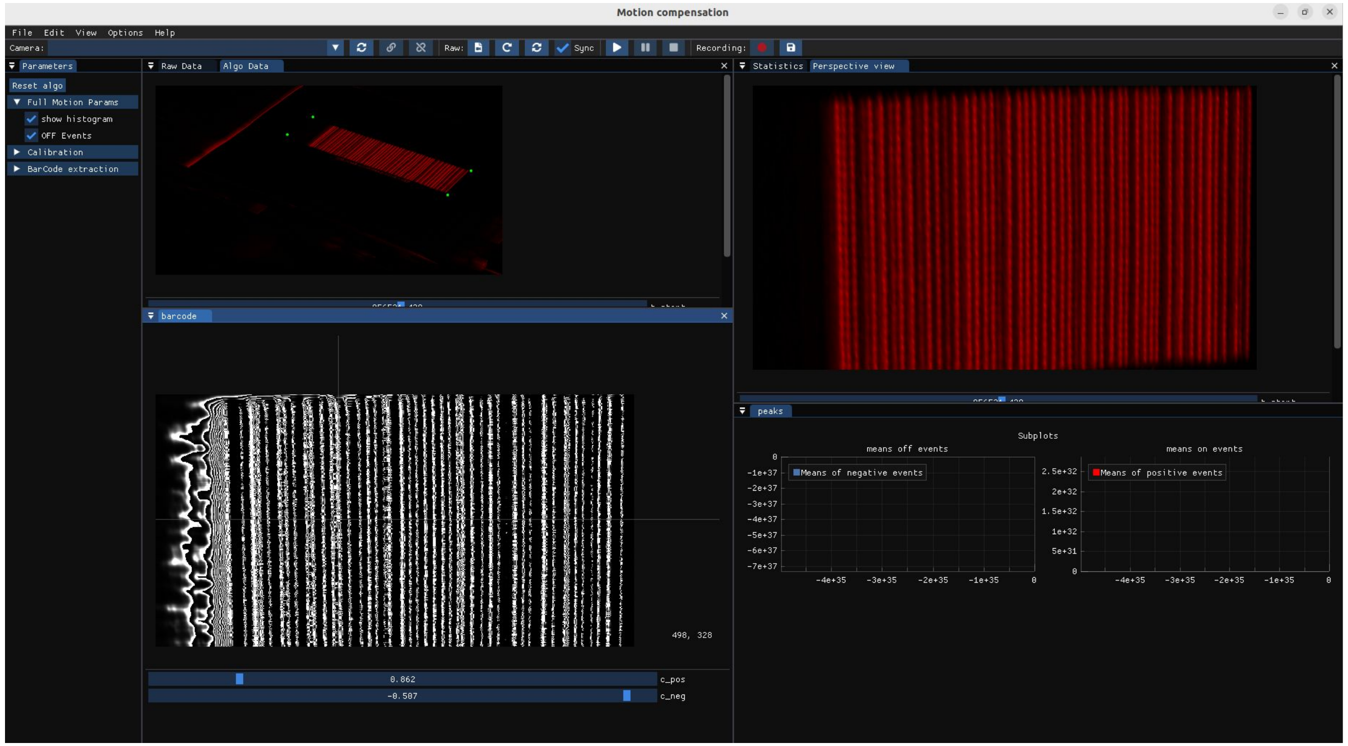
$$log \frac{I(t_1)}{I(t_0)} = \sum_{i \in \xi_{t_0,t_1}} c_i = n_- c_- + n_+ c_+$$

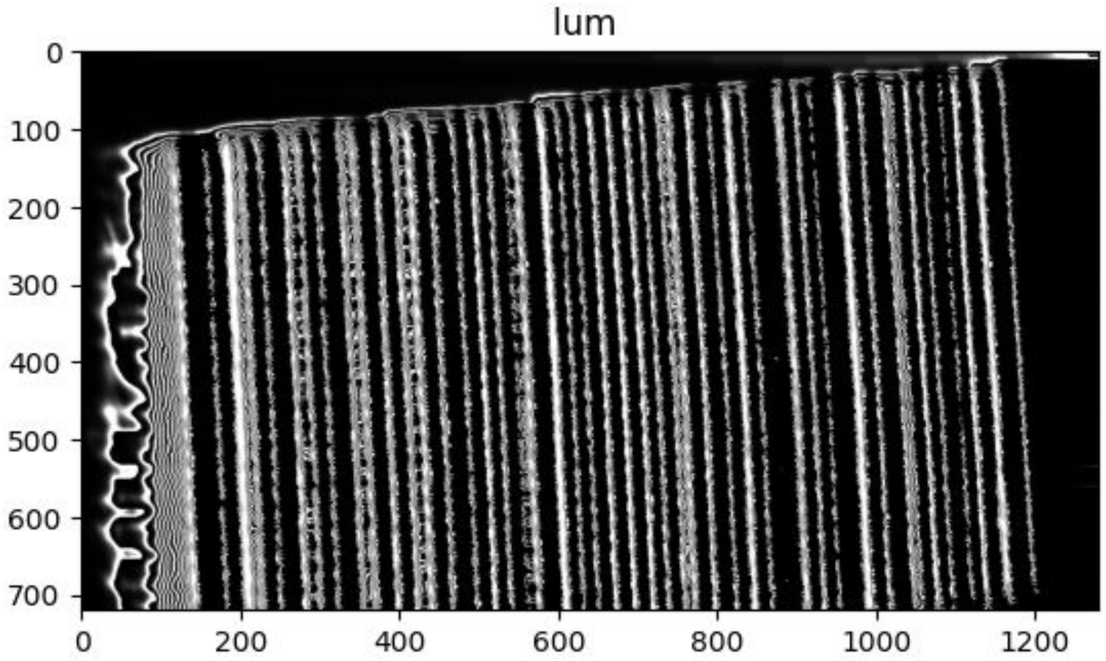
- Where c-, c+ respectively are the negative and positive contrast thresholds, and n-, n+ are the negative and positive event counts.

Gray scale image without considering the history of the previous pixels



Exponential integration with considering the previous pixel





Numerical saturation when using the exponential

Future Work

- Continue working on the luminance image
- Creating a grayscale image from the histogram

Thank you for your attention


PROPHESEE
METAVISION FOR MACHINES