Speed Invariant Time Surface for Learning to Detect Corner Points with Event-Based Cameras

Jacques Manderscheid, Amos Sironi, Nicolas Bourdis, Davide Migliore, Vincent Lepetit

PROPHESEE, Paris • University of Bordeaux, Bordeaux • France

EVENT-BASED CAMERAS

TIME

Event-based acquisition | Frame-based acquisition

- **A paradigm shift in the representation of movement**
  - Low latency: sub-millisecond accuracy
  - Low energy and memory consumption
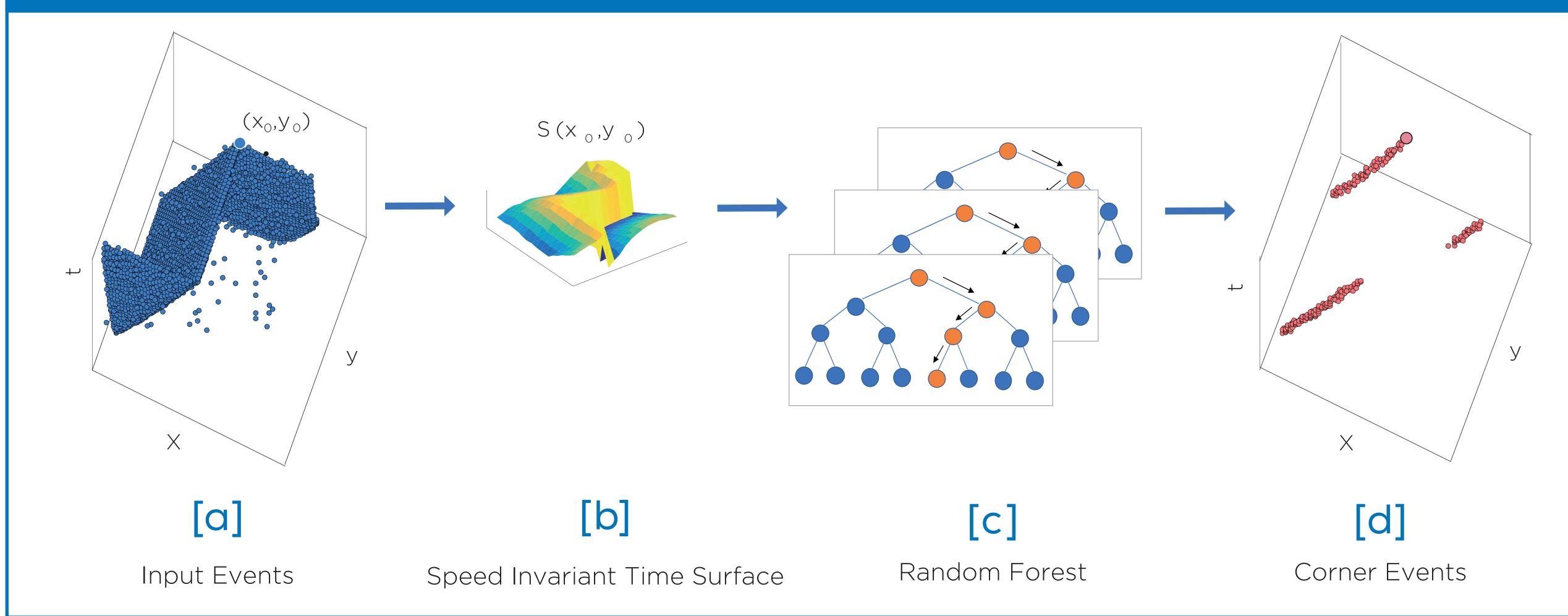 - High dynamic range (>120dB)

- **Asynchronous Time-based Image Sensor (ATIS)**
  - Pixels independently respond to illumination changes
  - Asynchronous grayscale measurements (used in this work only for ground truth generation)

PIXEL ILLUMINANCE

CHANGE-DETECTION EVENTS

GRAYSCALE EVENTS

OVERVIEW OF THE PROPOSED METHOD

(x_0, y_0) $S(x_0, y_0)$

[a] Input Events   [b] Speed Invariant Time Surface   [c] Random Forest   [d] Corner Events

SPEED INVARIANT TIME SURFACE

- **Standard Time Surface**
  - For every input event $e_i = (x_i, y_i, t_i, p_i)$, $T(x_i, y_i, t_i, p_i) \leftarrow t_i$
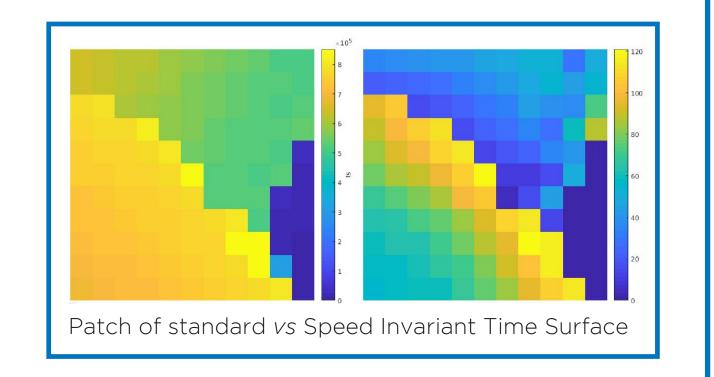 - Highly dependent to the velocity of the corners

- **Efficient event-based normalization inspired by a sorting algorithm**
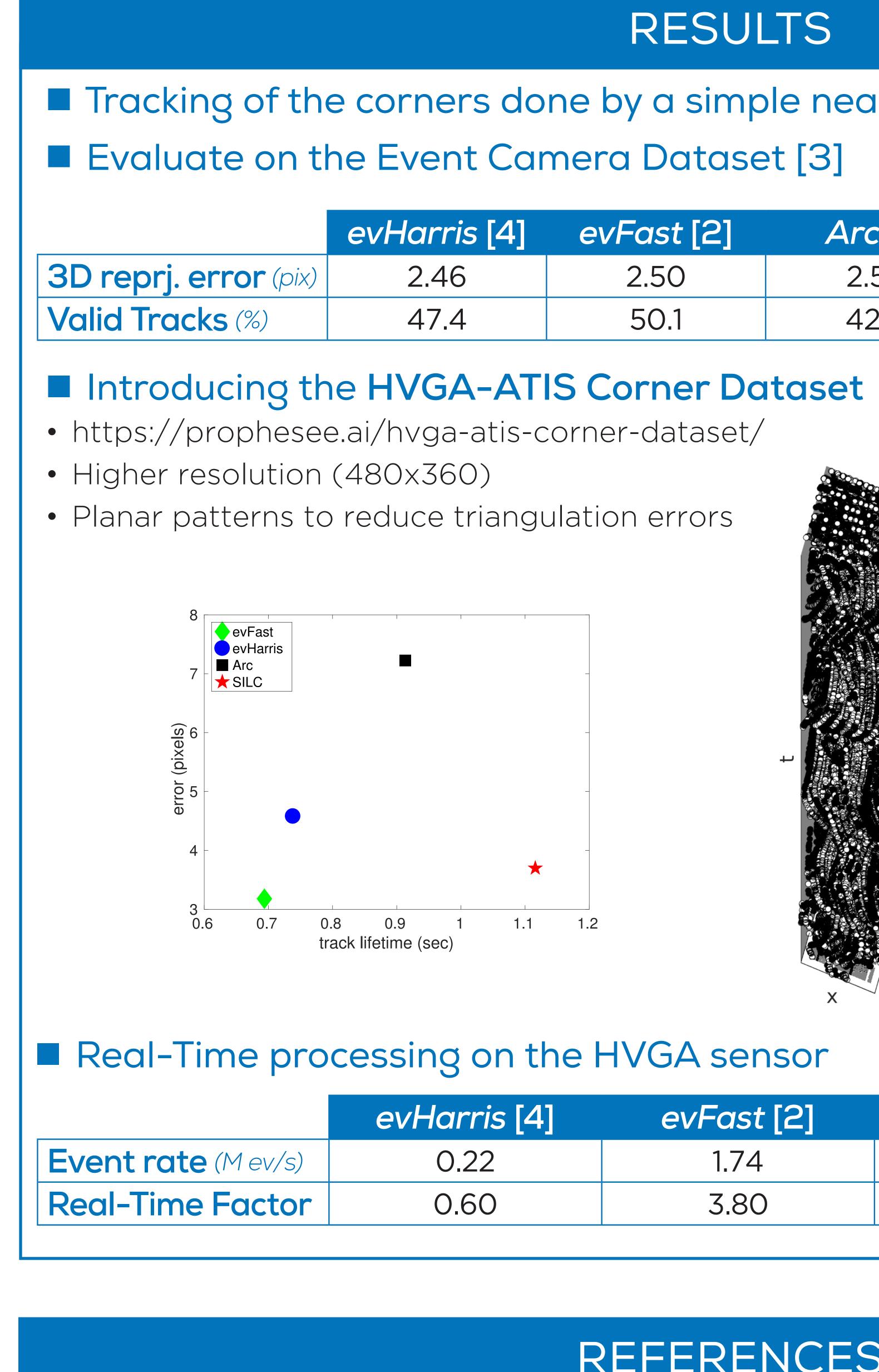
1. Output: **Speed Invariant Time Surface** $S(x, y, p)$;
2. Initialization: $S(x, y, p) \leftarrow 0$ for all (x, y, p);
   for each incoming event (x, y, p), update S do
     for $-r \leq dx \leq r$ do
       for $-r \leq dy \leq r$ do
         if $S(x + dx, y + dy, p) \geq S(x, y, p)$ then
3. $S(x + dx, y + dy, p) \leftarrow S(x + dx, y + dy, p) - 1$;
4. $S(x, y, p) \leftarrow (2r + 1)^2$;

Patch of standard vs Speed Invariant Time Surface

LEARNING THE CORNER DETECTOR

- **Building a dataset with ground truth**

For every input event $e_i = (x_i, y_i, t_i, p_i)$
- Extract a patch from the Speed Invariant Time Surface
- Apply the Harris corner detector on the gray levels at its location to get the ground truth

RESULTS

- Tracking of the corners done by a simple nearest neighbor
- Evaluate on the Event Camera Dataset [3]

	evHarris [4]	*evFast* [2]	*Arc* [1]	SILC ATIS	SILC DAVIS
3D reprj. error *(pix)*	2.46	2.50	2.58	2.53	2.16
Valid Tracks *(%)*	47.4	50.1	42.9	47.3	65.3

- **Introducing the HVGA-ATIS Corner Dataset**
  - https://prophesee.ai/hvga-atis-corner-dataset/
  - Higher resolution (480x360)
  - Planar patterns to reduce triangulation errors

- **Real-Time processing on the HVGA sensor**

	evHarris [4]	*evFast* [2]	*Arc* [1]	SILC
Event rate *(M ev/s)*	0.22	1.74	5.61	1.61
Real-Time Factor	0.60	3.80	12.32	3.53

REFERENCES

[1] Ignacio Alzugaray and Margarita Chli. Asynchronous corner detection and tracking for event cameras in real time. *IEEE Robotics and Automation Letters*, 2018.

[2] Elias Mueggler, Chiara Bartolozzi, and Davide Scaramuzza. Fast event-based corner detection. In *BMVC*, 2017.

[3] Elias Mueggler, Henri Rebecq, Guillermo Gallego, Tobi Delbruck, and Davide Scaramuzza. The event-camera dataset and simulator: Event-based data for pose estimation, visual odometry, and slam. *The International Journal of Robotics Research*, 2017.

[4] Valentina Vasco, Arren Glover, and Chiara Bartolozzi. Fast event-based harris corner detection exploiting the advantages of event-driven cameras. In *Intelligent Robots and Systems (IROS)*, 2016 IEEE/RSJ International Conference on, 2016.

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