Miniaturized embedded event based vision for high-speed robots

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Neuroscientific System Theory

Competence Center NeuroEngineering

Technische Universität München

http://www.nst.ei.tum.de

Center of Competence Neuroengineering

NEUROSCIENTIFIC SYSTEM THEORY
Technische Universität München

Retinal Inspired Dynamic Vision Sensor

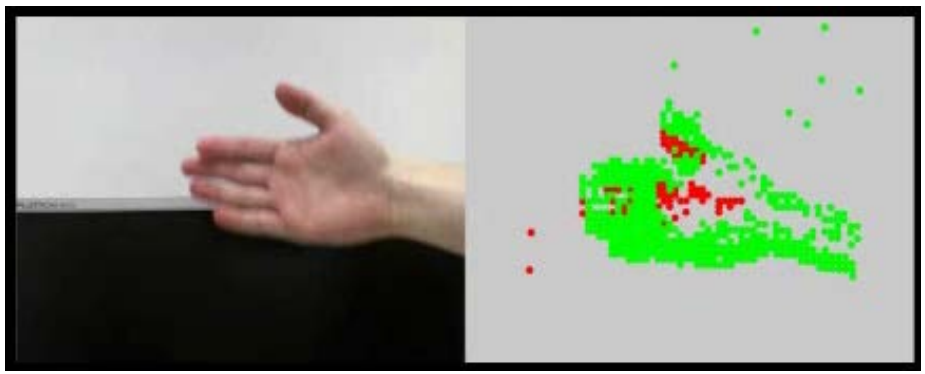
Sensor Features

- Pixel signal temporal changes of illumination (“events”)
- Asynchronous updates (no image frames)
- Few microseconds latency, up to 1Mevents/sec

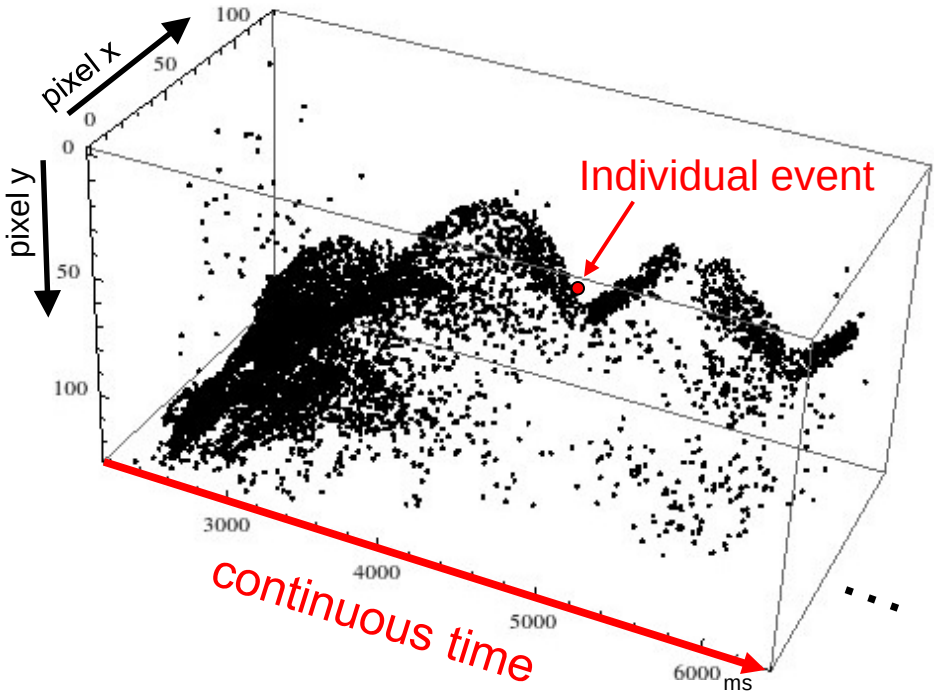
DVS128 sensor

Advantages

- Sparse data stream (~200 kEvents / sec)
- Ultra-low response time (~15 us)
- Local contrast adjustment per pixel
  → ~120dB dynamic illumination range



Video camera DVS reconstruction

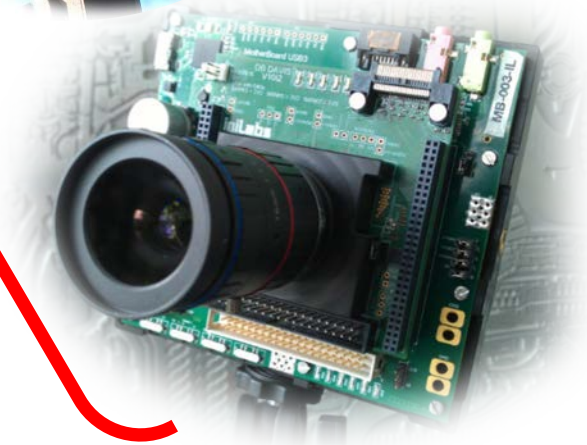


Available DVS Sensors

DVS128

DAVIS240

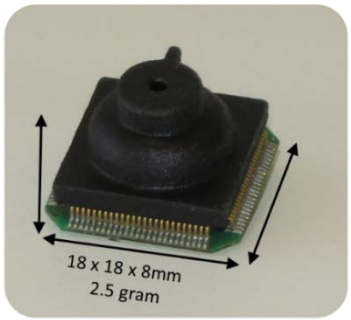
USB

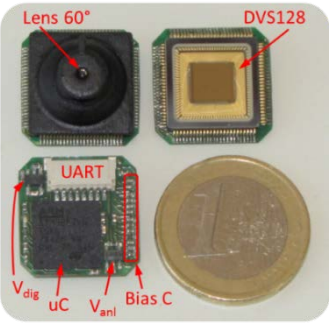


DAVIS640

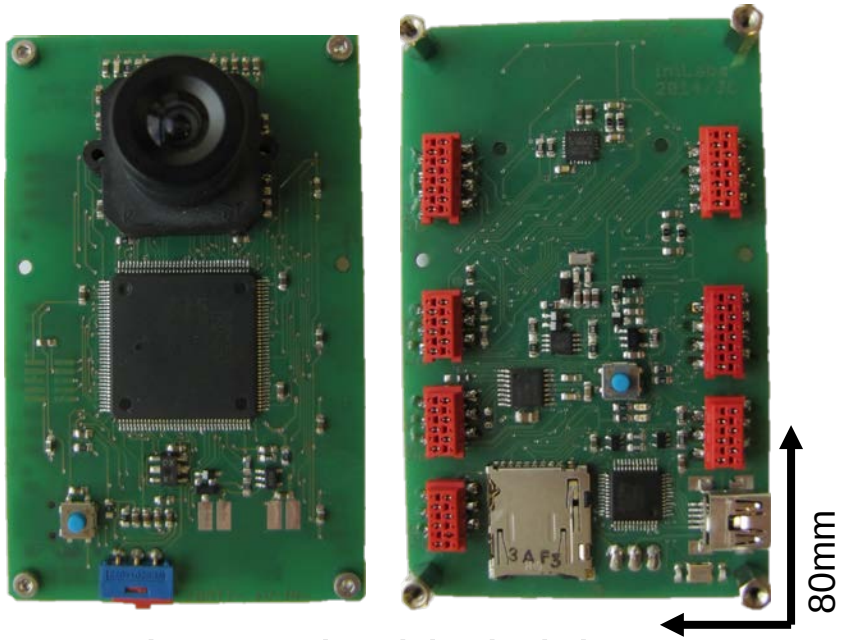
Embedded DVS Systems (eDVS)

developed at





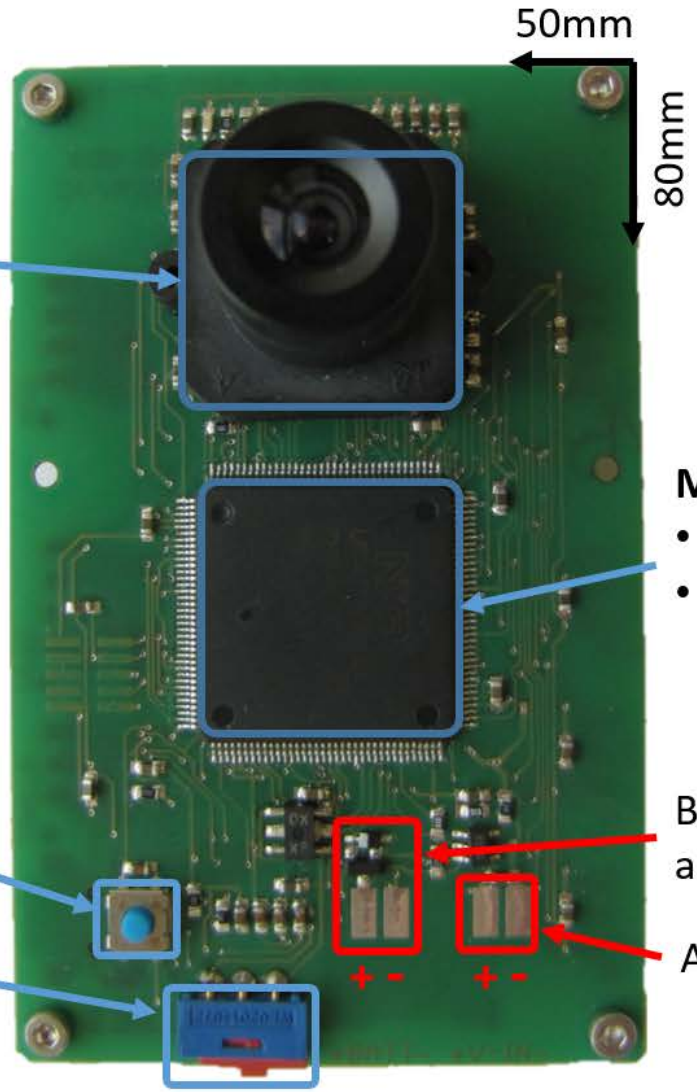
Size and weight improved



Real-time embedded vision and autonomous motor control

Embedded DVS Sensors

What's on the board?



Microcontroller LPC4337 32bit ARM Cortex
- M0 for event fetching & data transmission
- M4 available for custom application, up to 204MHz, 136KB SRAM (104KB available)

Battery charging circuitry, auxiliary LiPo battery connector

Auxiliary power input, 4-6V

Embedded DVS Sensors

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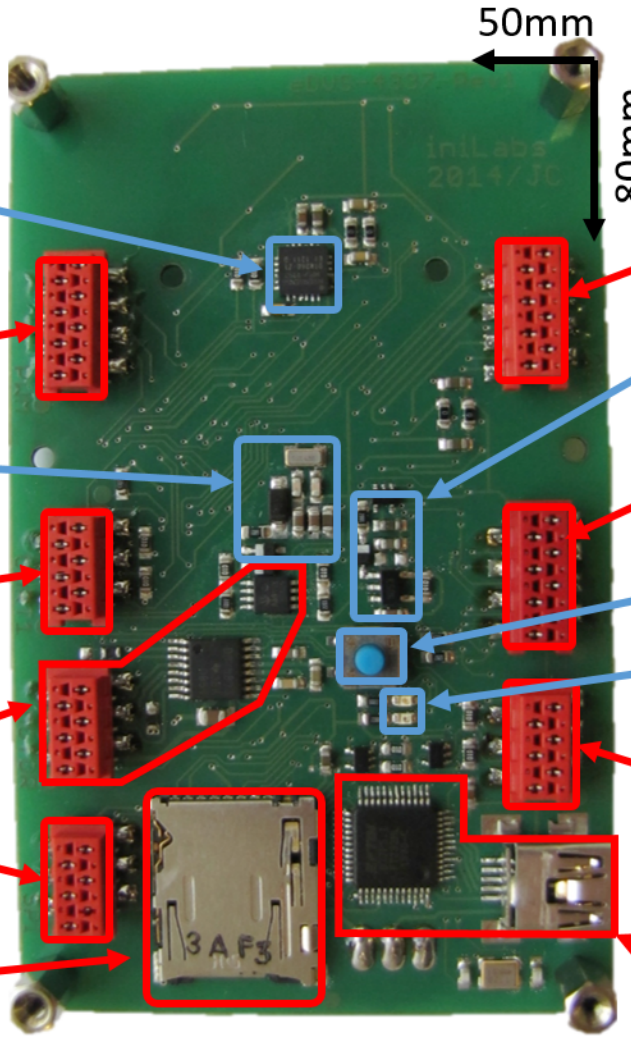


MPU-9150 Nine-Axis IMU
(Gyro + Accelerometer + Compass)

PWM Outputs (non-amplified)
3x2 channels

Real-Time-Clock (RTC) support

UART1 (high speed, up to 12Mbps)
master pin-out (for cascading boards)

Dual-channel high-current
motor driver+sensor (PWM)

SPI Connector

microSD card slot
(≤4GB files for long-time recordings)

ADC Inputs, 6 channels (0 - 2.8V)

"Wake-up on activity" circuitry
(deep sleep power-safe mode)

General purpose I/O (0 - 2.8V)
6 digital input/output pins

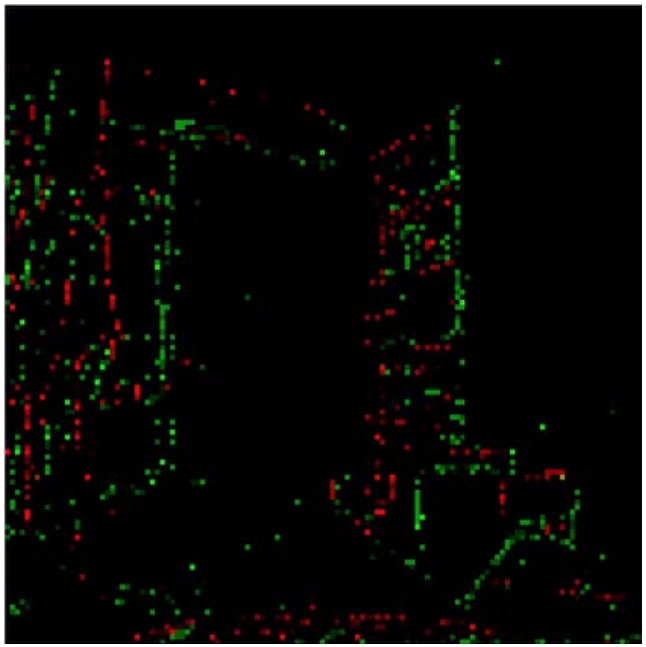
Reset Button

2 Status LED (red/green)

UART0 (high speed, up to 12Mbps)
(shared with USB)

UART0 - USB converter (FTDI232HL)
(shared with UART0)
provides power for eDVS4337;
allows re-charging a connected battery

Event-based Data Format



Reconstructed video sequence
from raw DVS data

vs.

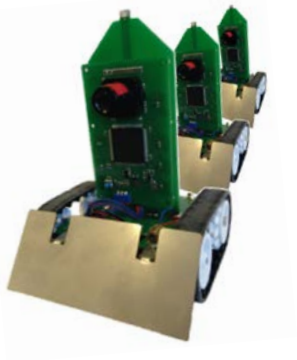
(x)	(y)	(p)	(time)
:	:	:	:
:	:	:	:
:	:	:	:
50	112	1	13437757
43	114	0	13437762
73	18	1	13437766
62	57	0	13437768
47	123	1	13437774
75	65	0	13437780
64	55	1	13437784
47	118	0	13437790
50	111	1	13437792
43	113	0	13437793
49	112	0	13437799
51	109	1	13437801
50	107	0	13437805
56	88	1	13437820
47	109	0	13437823
59	69	0	13437830
50	92	0	13437843
75	17	0	13437847
49	116	1	13437852
50	105	0	13437855
:	:	:	:
:	:	:	:
:	:	:	:

time

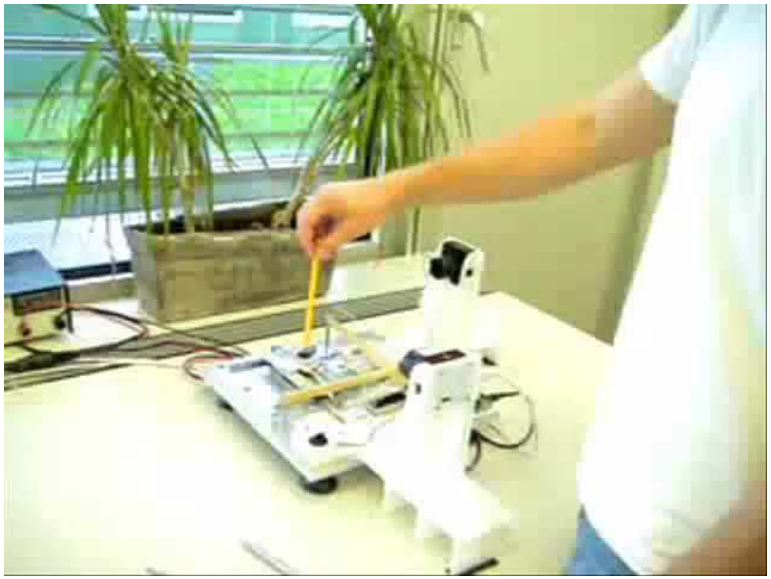
raw DVS data

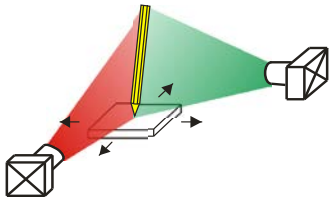
address
event
representation
(AER)

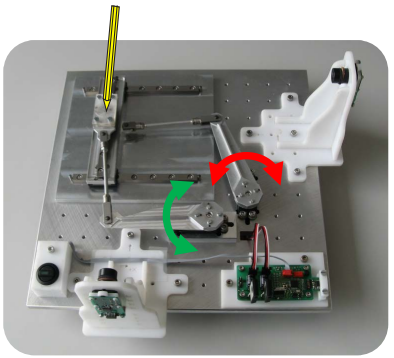
Engineering (Student) Fun with eDVS



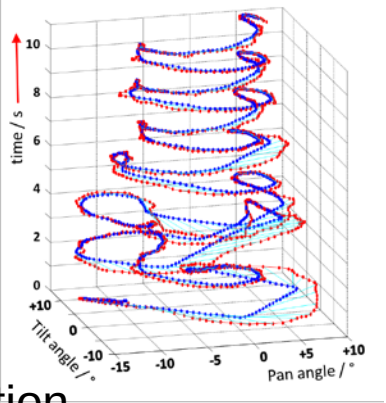
Mobile robot chain



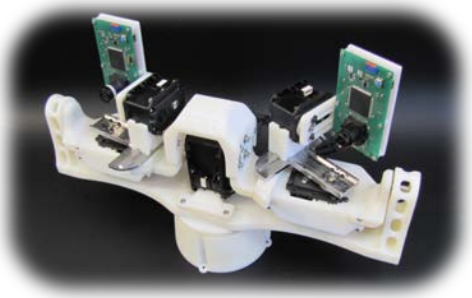




High-speed balancing miniature poles (pencils)

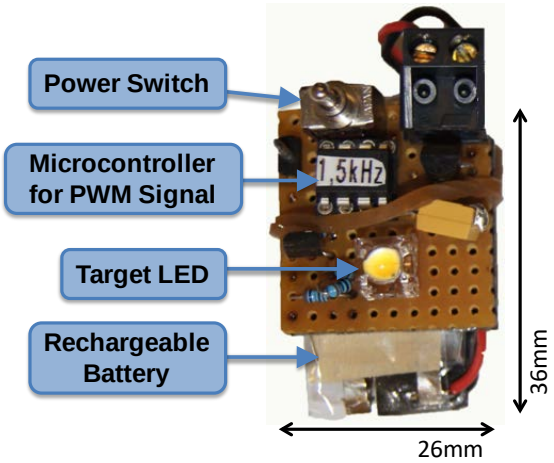


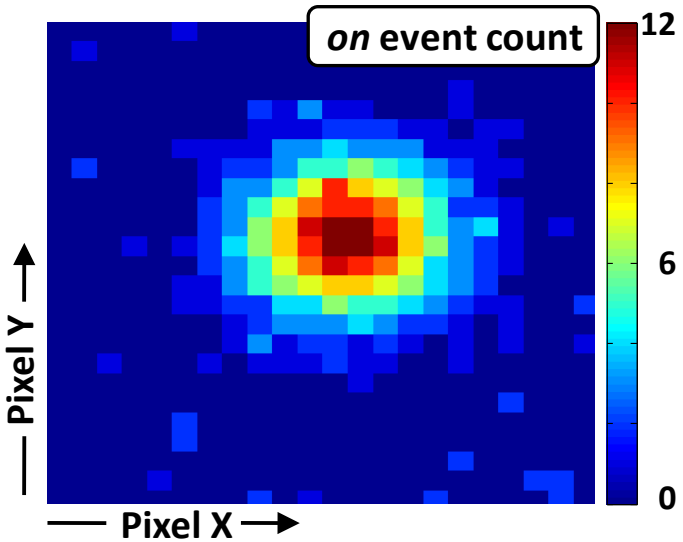
Tracking ‘unpredictable’ motion

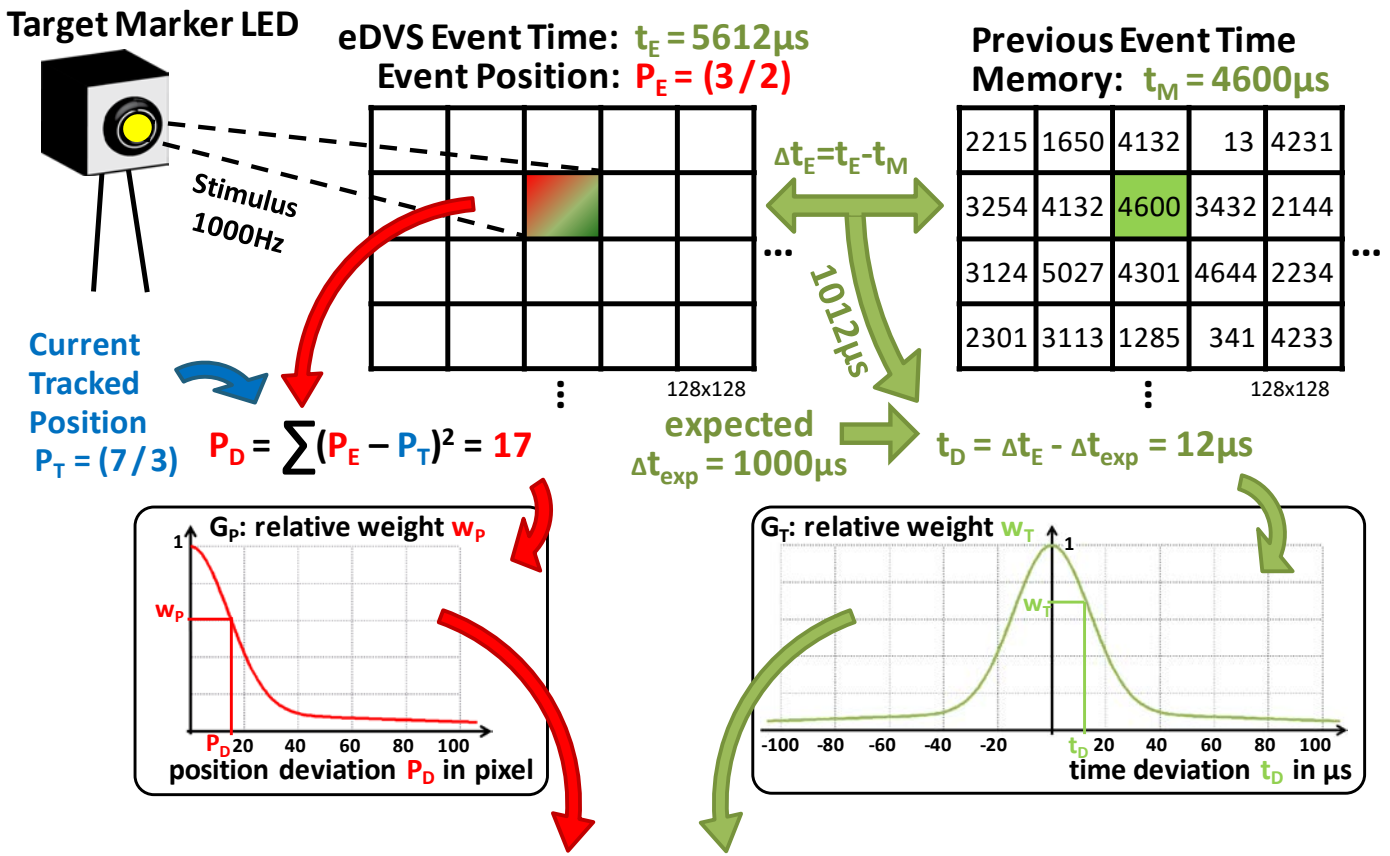


Oculomotor control, saccades and smooth pursuit

Application Example: Tracking an Active Object

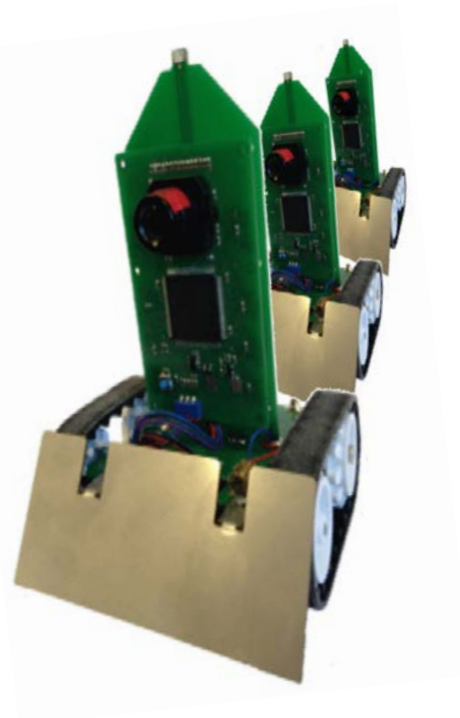




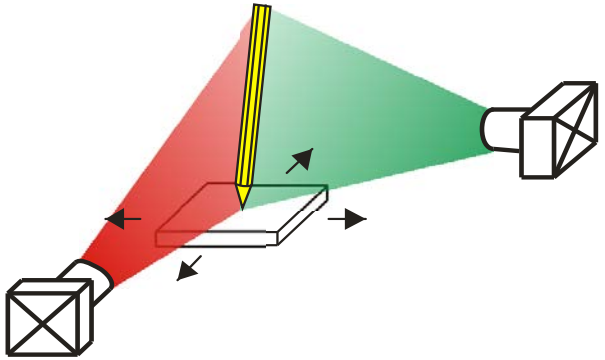


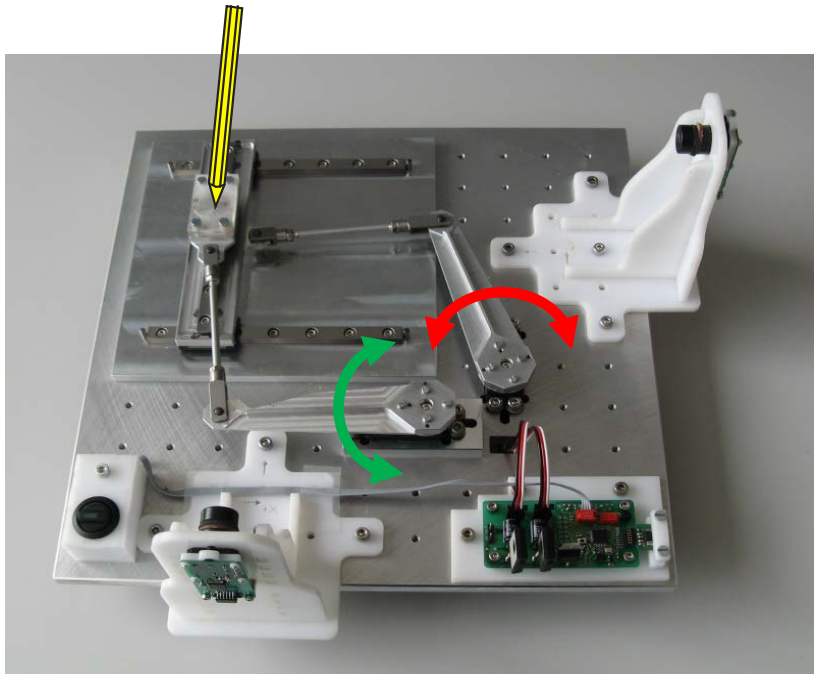
Position Update: $P_{T+1} = (1 - \eta(w_T + w_P)) \cdot P_T + \eta(w_T + w_P) \cdot P_E$

Student Project – Robot Chain



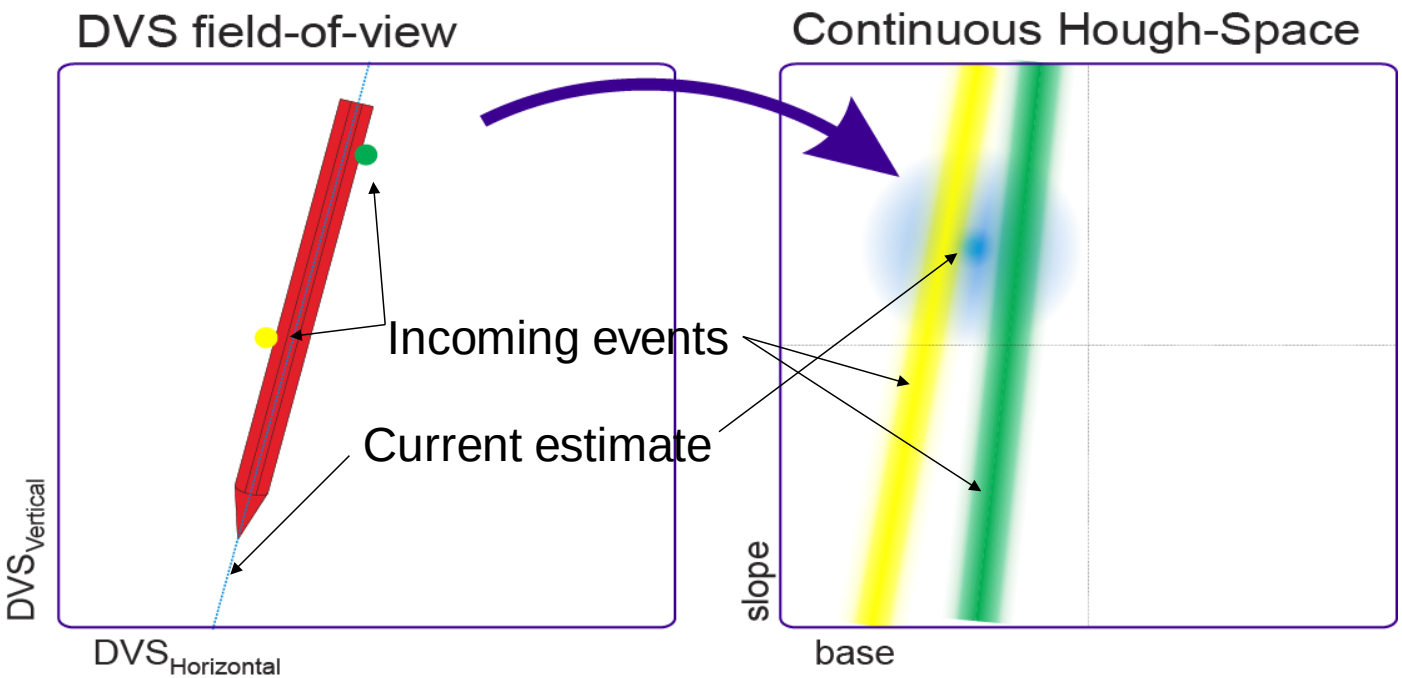
(Fun) Application Example: High Speed Balancing of Short Poles

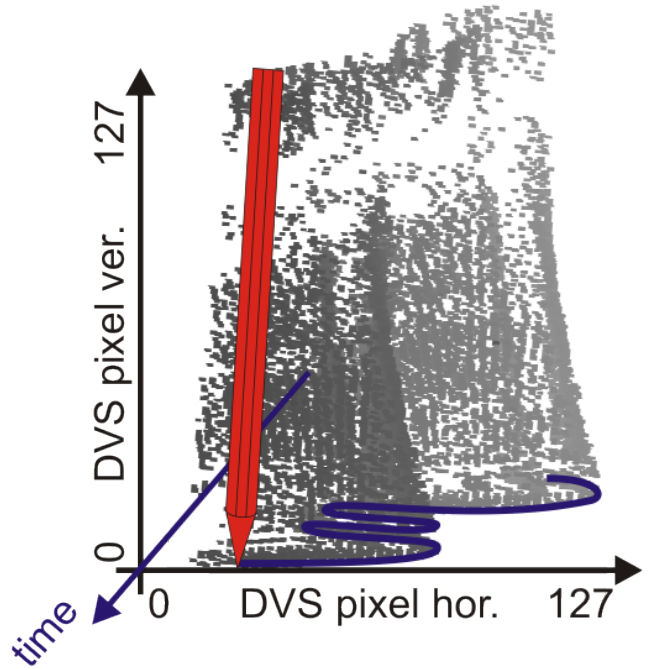




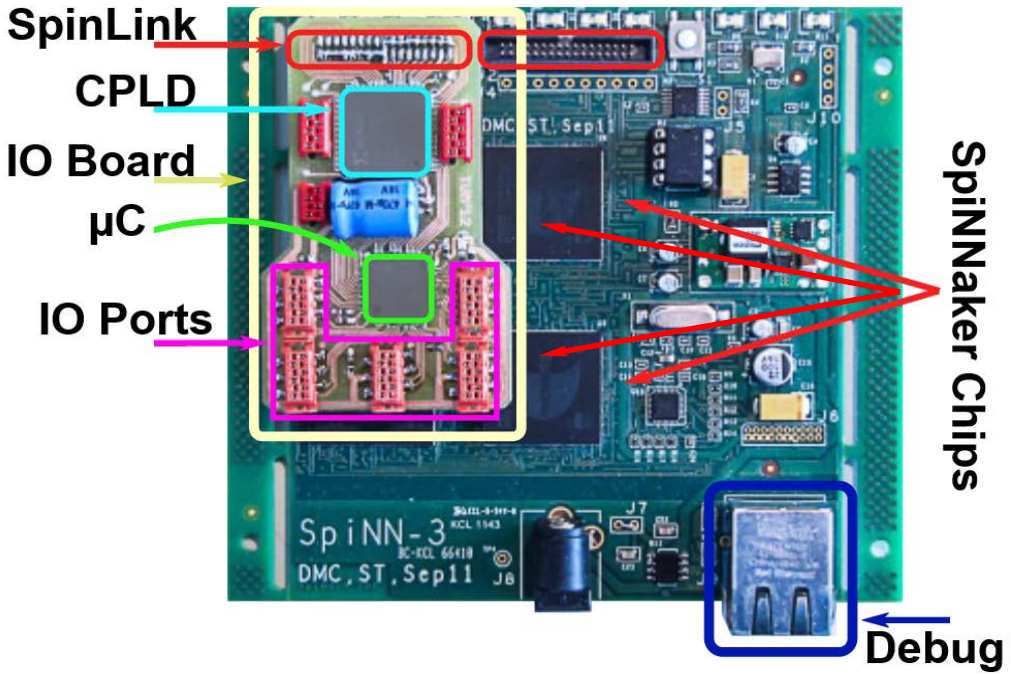
(Fun) Application Example: High Speed Balancing of Short Poles

Converting Events into Meaning

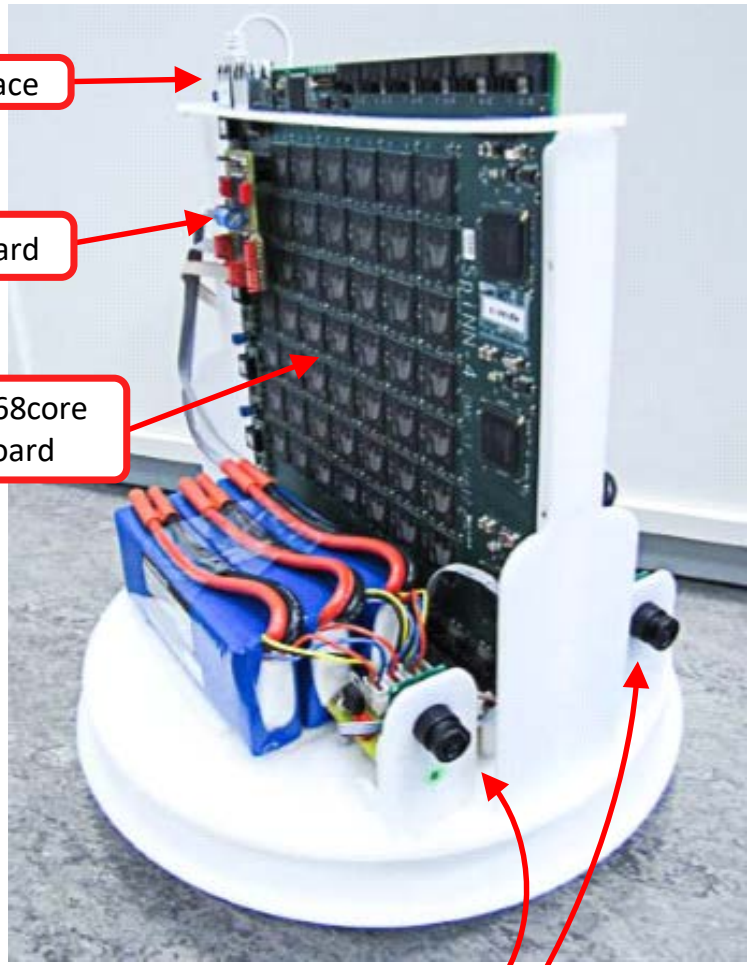


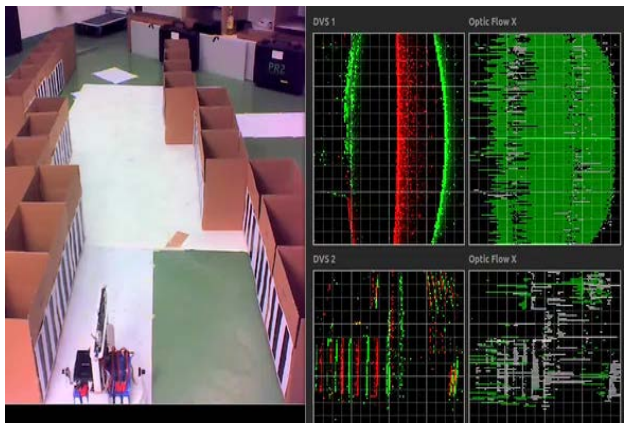


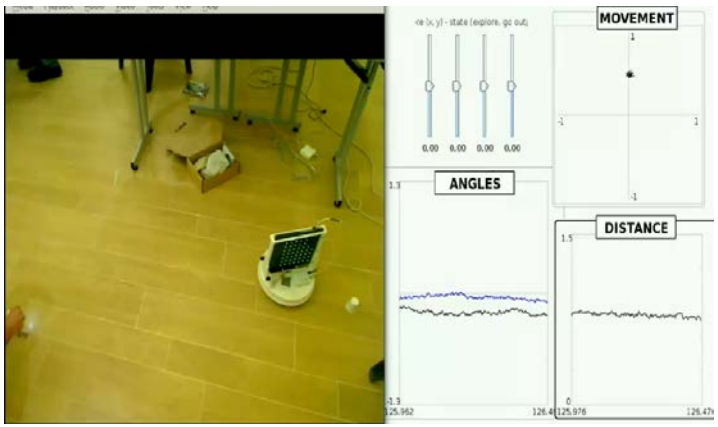
SpiNNaker Real-Time Hardware Interface



NST SpomniBot





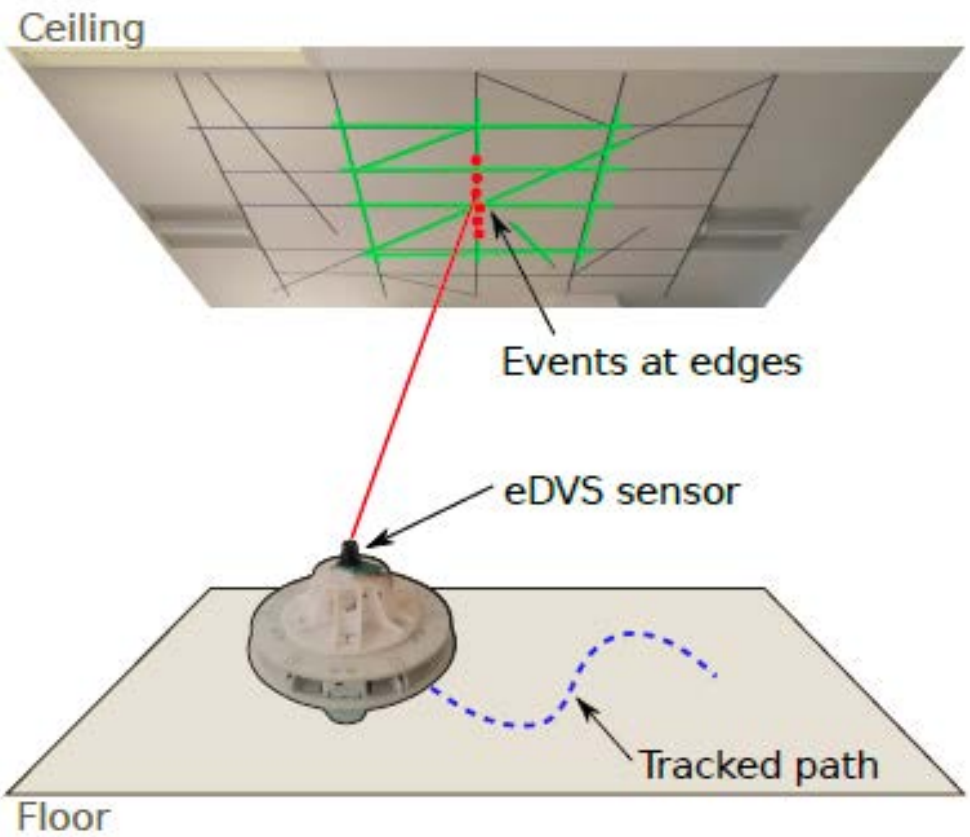


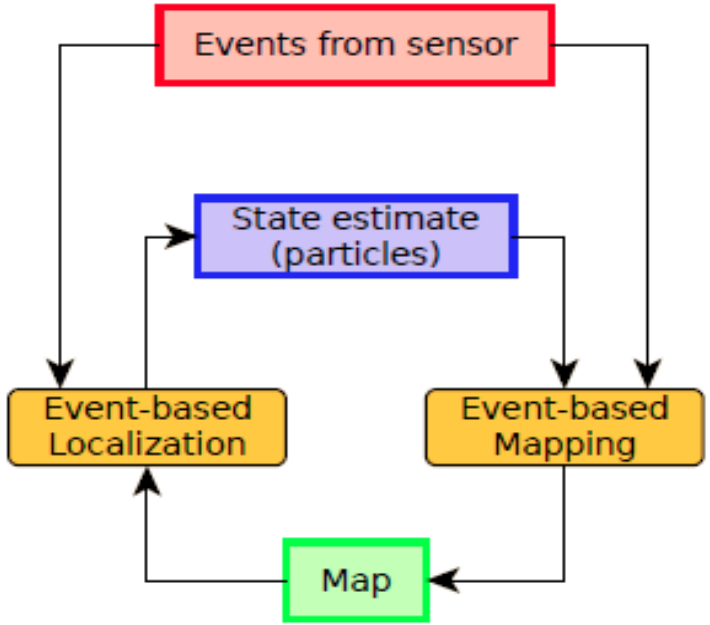
• Galluppi, F.; et. al. Event-based neural computing on an autonomous mobile platform, IEEE ICRA 2014, p. 2862-67

• Denk, C., et al, Real-Time Interface Board for Closed-Loop Robotic Tasks on the SpiNNaker Neural Computing System. ICANN 2013, p. 467-74.

SLAM for embedded Event-Based Vision Systems

Event-based Particle Filter





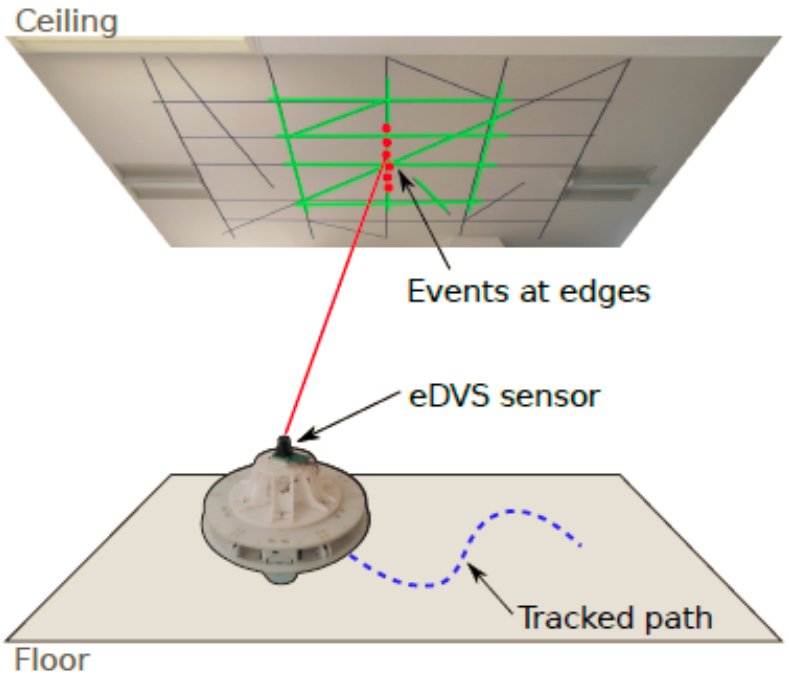
Event-based Particle Filter Framework

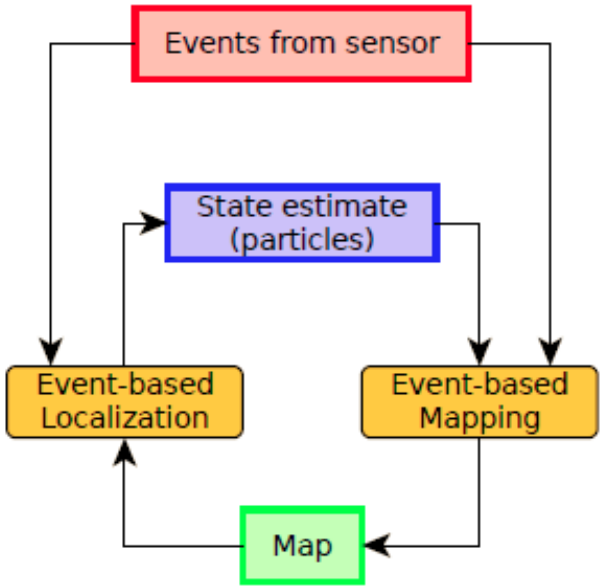
- Every event used to incrementally build a map
- Every event used to incrementally update estimate of quality of particles

→ computationally efficient framework

- Weikersdorfer, D.; Hoffmann, R.; Conradt, J.: Simultaneous Localization and Mapping for event-based Vision Systems. Intl. Conf. Computer Vision 2013, p. 133-42.
- Weikersdorfer, D.; Conradt, J.: Event-based Particle Filtering for Robot Self-Localization. IEEE International Conference on Robotics and Biomimetics (IEEE-ROBIO), 2012, p. 866-70.

SLAM for embedded Event-Based Vision Systems





5x real time

Hoffmann, R.; Weikersdorfer, D.; Conradt, J.: Autonomous Indoor Exploration with an Event-Based Visual SLAM System. ECMR, 2013, p. 38-43.

Autonomous Indoor Mini Quadrocopter

for real-time high-speed 3D SLAM

System Specifications

- 5 orthogonally mounted meDVS128
- On-board real-time vision processing in µController
- Complete take-off weight ~44 gram
- Autonomous flight for ~ 4 minutes

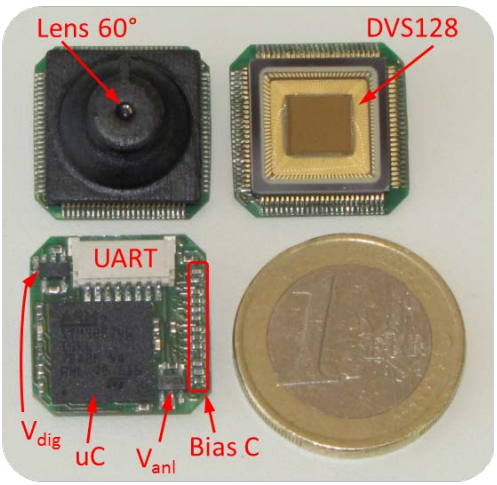
Applications

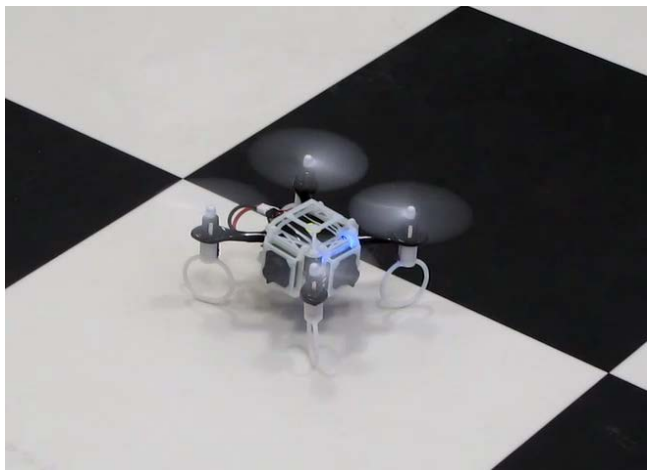
- First responder in search and rescue scenarios
- Autonomous exploration and mapping of indoor areas

Miniaturized embedded DVS

- 18x18x11mm, 2.3gram including optics
- 128x128 pixel @ 60° FOV
- 32bit ARM µC (216MHz, 512KB SRAM)
- Complete take-off weight ~44g
- ~300mW (2,8V @ 108mA full load)

Complete on-board autonomous high-speed vision processing





Everding, L. and Conradt, J., Persistent real-time line tracking using Event-Based Dynamic Vision Sensors, submitted to ICCV.

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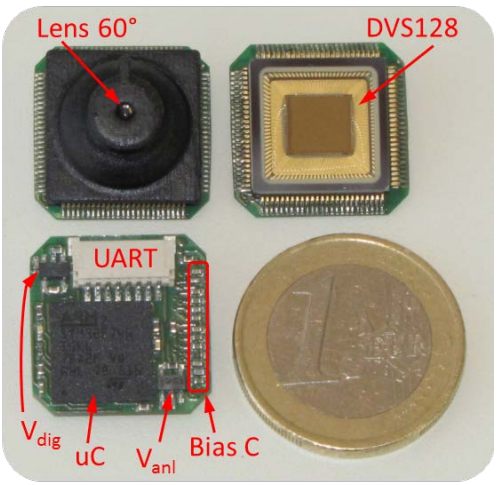

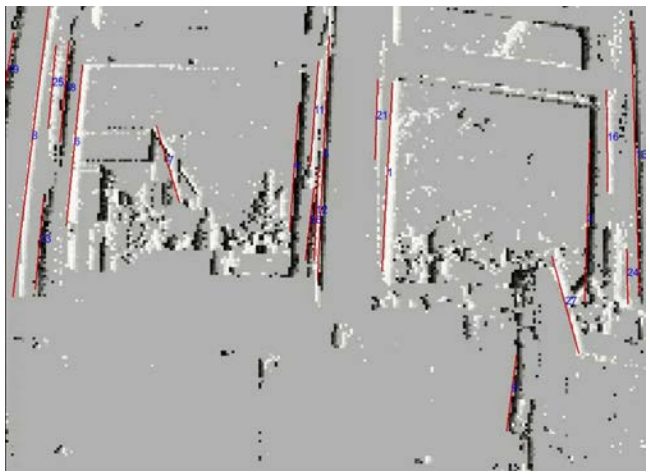

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Autonomous Indoor Micro Quadrocopter

We go even smaller

Micro Quadcopter

- 23 x 23 x 20 mm
- 7g total weight
- 4min flight

Micro eDVS

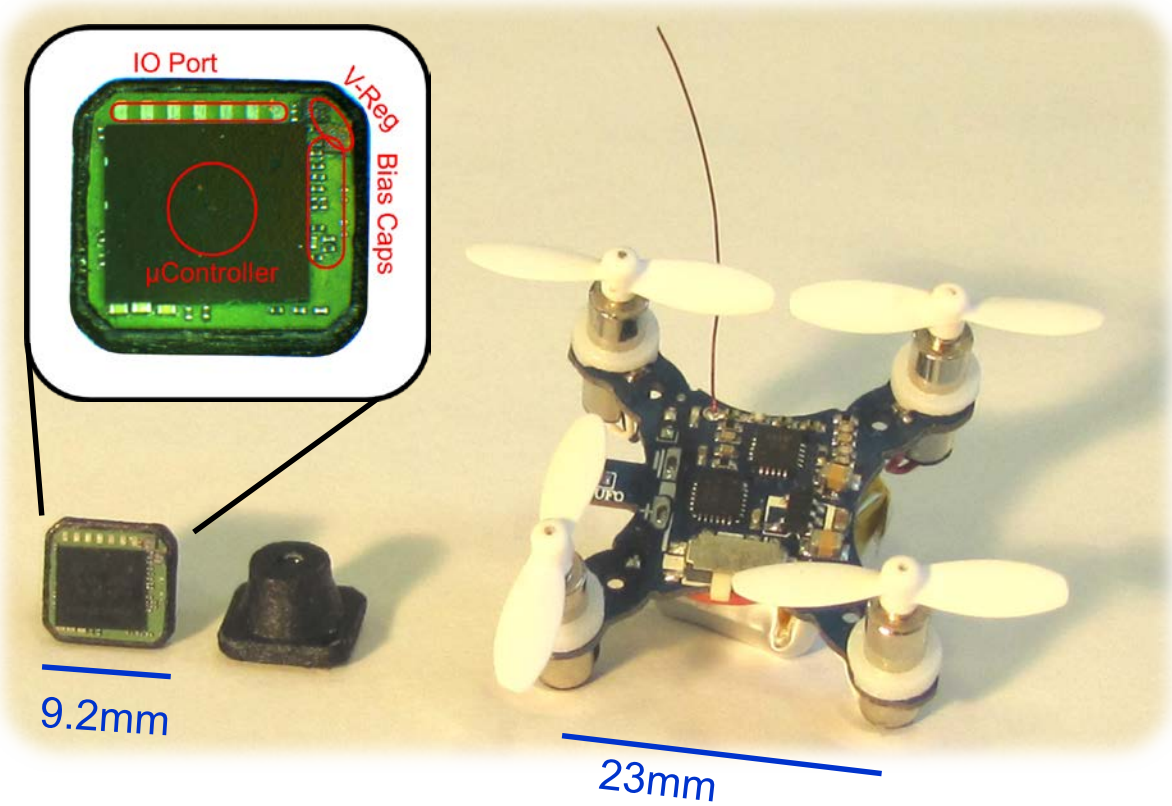
- 9.2 x 8.4 x 6.8 mm
- 0.240g total weight
- Electrically identical to meDVS

How small can we go? see

Harvard / WYSS Institute
Robo Bee Project

Exploits various eDVS Benefits

- Low latency, agile flight maneuvers possible
- Low energy and computing requirements
- Operates in drastically differing light conditions

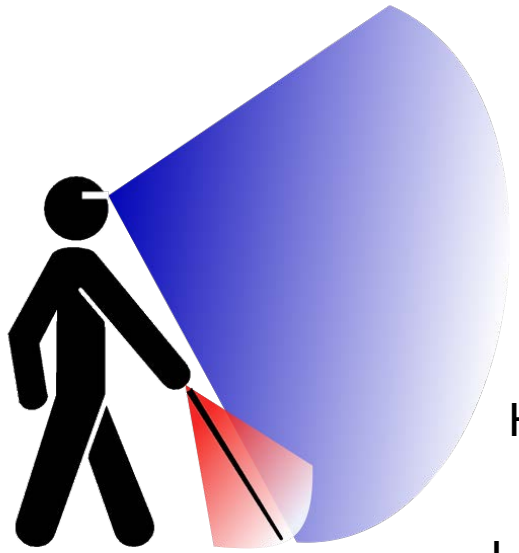


eDVS for Healthcare

NEUROGLASSES
Beyond mobility

1st prize Feb 2015
TUM IdeAward

A portable device to help the visually-impaired



Intuitive

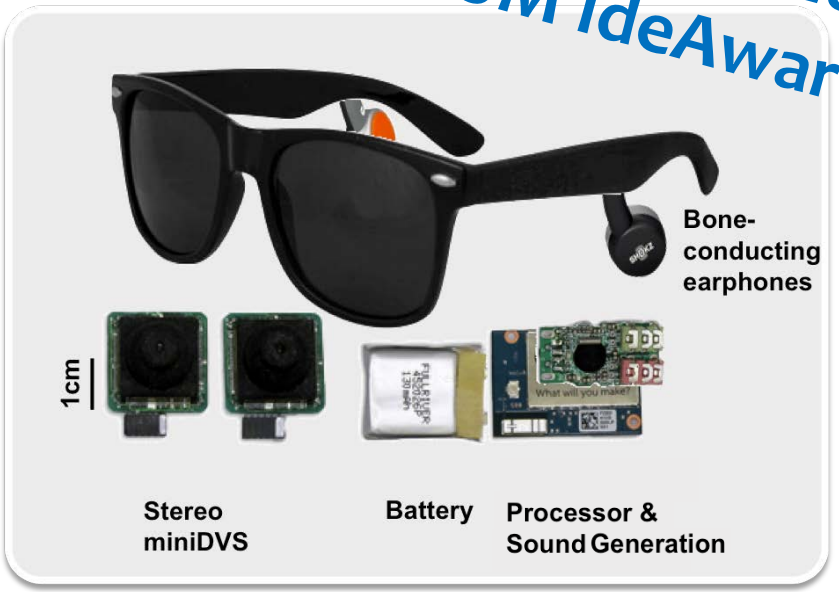
Low cost

Light-weight

Hands-free

Ears free
for regular hearing

Long
battery lifetime



SpinOff Prototype

AuvioNav
AuvioLab

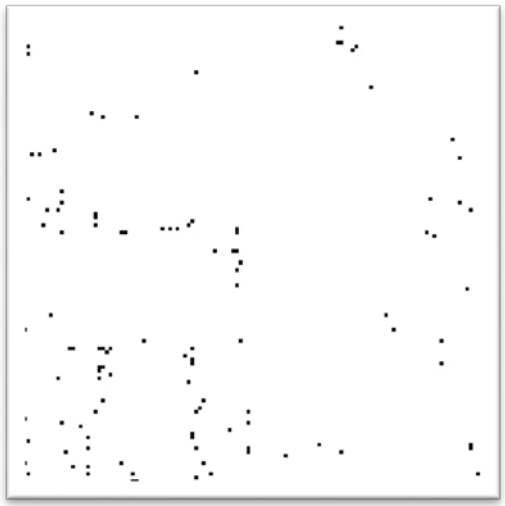
Feedback: Substantially increased autonomy,
therefore higher quality of live!

Patent Assistive device and system to provide 3D spatial perception to the visually-impaired by translating event-based visual information into 3D auditory scenes (filed 16.2.2015, published 25.8.2016)

NST

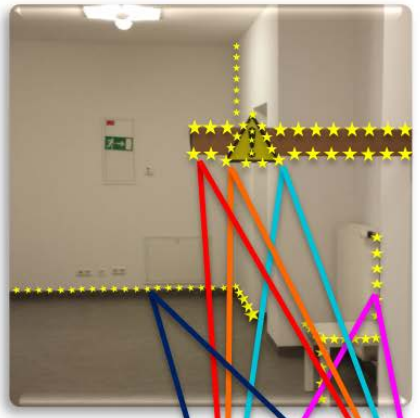
eDVS for Healthcare

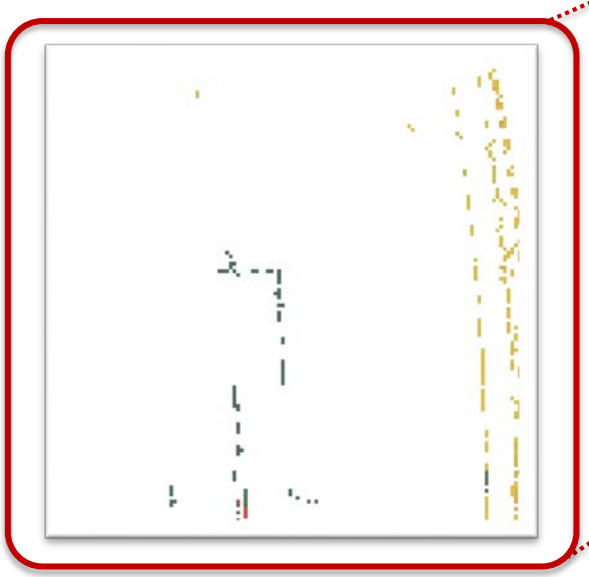
NEUROGLASSES
Beyond mobility



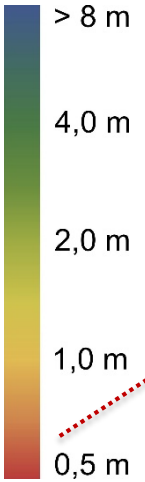
Left eDVS

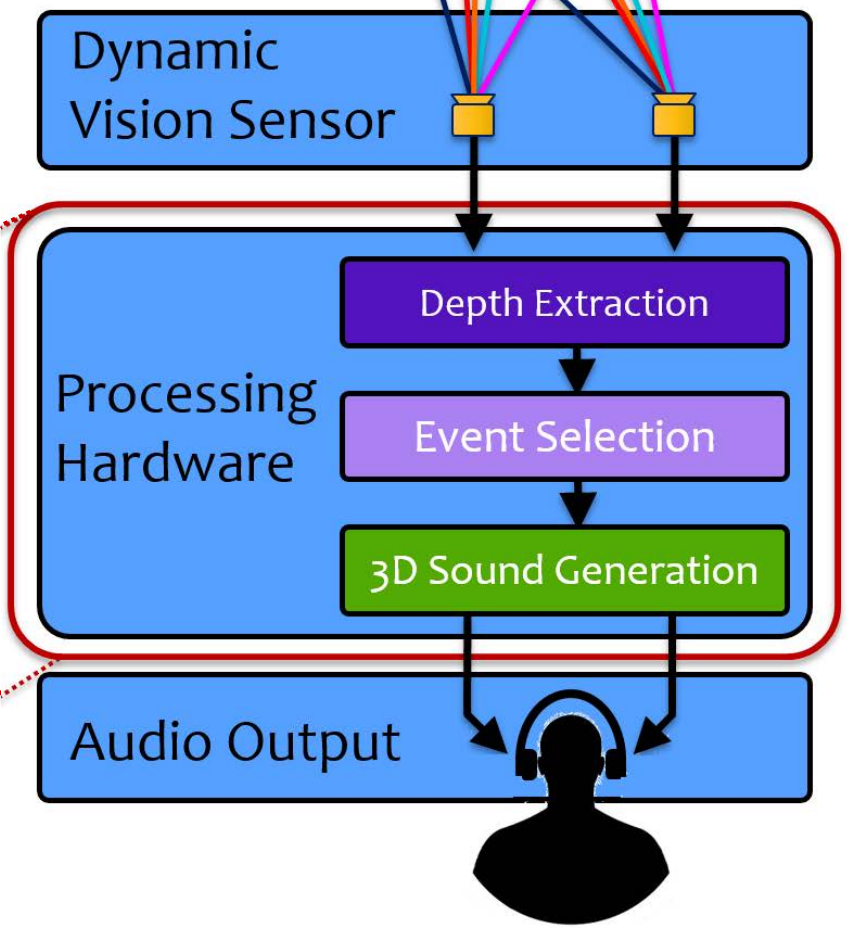
Right eDVS





Depth image





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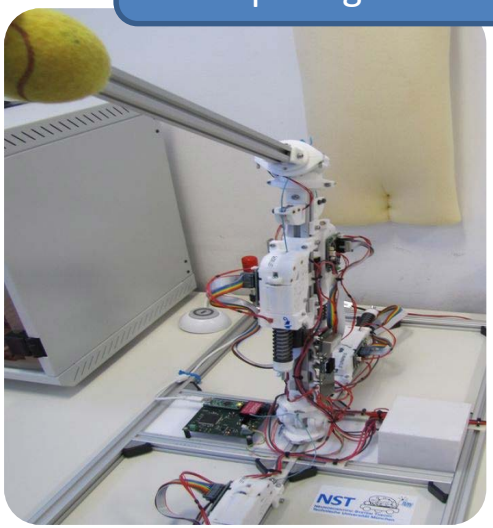
NST

Real-Time Neuronal Information Processing in Closed-Loop Systems

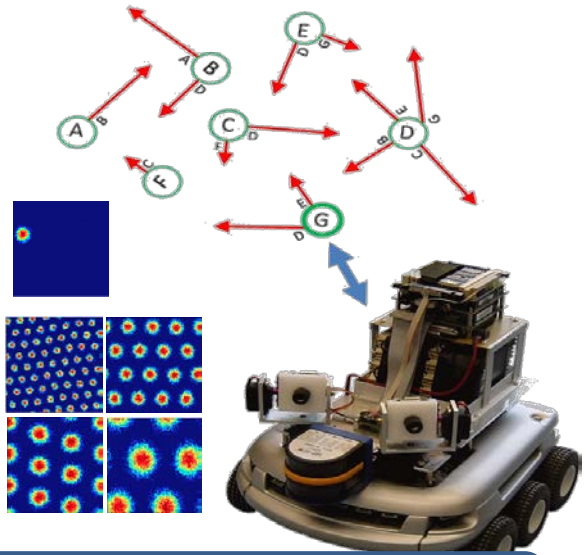
- **Event-Based Neuromorphic Vision**
- Information Processing in Distributed Neuronal Circuits
- Neuromorphic Real-Time Computing and Control
- Self-Construction and Organization of Neuronal Circuits

Event-Based Neuromorphic Vision

Neuromorphic Real-Time Computing and Control



Information Processing in Distributed Neuronal Circuits



Self-Construction and Organization of Neuronal Circuits

Neural Principles for Real-Time System Engineering