Miniature visual motion sensors

F. L. Roubieu, F. Expert, S. Viollet and F. Ruffier

Biorobotics Dpt.
Institute of Movement Sciences (Marseille, France)
Aix-Marseille Univ. / CNRS

10th November 2011

Outline

Optic flow definition

Part 1 : Time of travel processing and optical characterization

Part 2 : Linear pixels versus Adaptive pixels

Part 3 : Time of travel processing versus Mouse sensor

Part 4 : Stand alone 1-gram device of the visual motion sensor

Conclusion

Optic flow definition

-> Winged insects use optic flow, ω, to navigate

Visual motion sensor / Local Motion Unit (LMU)  *Franceschini 2003*	**1992**   *Blanes (1986)* *Franceschini et al. (1992)*	**2003**   *Ruffier et al. (2003)*
Mass (g/LMU)	6	2.5
Size (mm^2/LMU)	1260	500
Power consumption (mW/LMU)	100	40
Number of LMU	1	1

Optic flow sensors

Ruffier et al. (2003) IEEE ISCAS

Beyeler, Zufferey and Floreano 2005

No full characterization of optic flow sensors :

- Influence of illuminance changes
- Outdoors and indoors
- Refresh rate

Barrows, Centeye

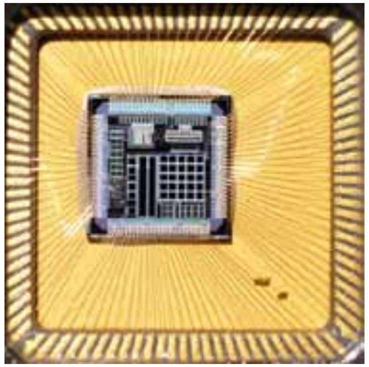
Tested sensors

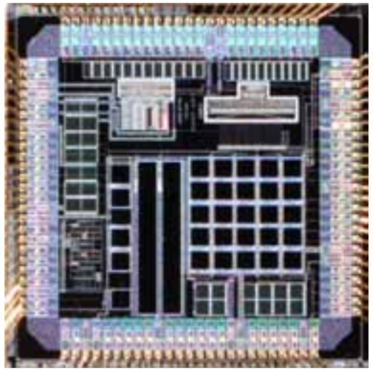
LSC : Linear array from IC-HAUS company

- Linear on-chip preamplification circuit

- 6 pixels

Adaptive Pixels for Insect-based Sensors (APIS)





Viollet et al. (2010) Proc. of SENSORCOMM Conf.

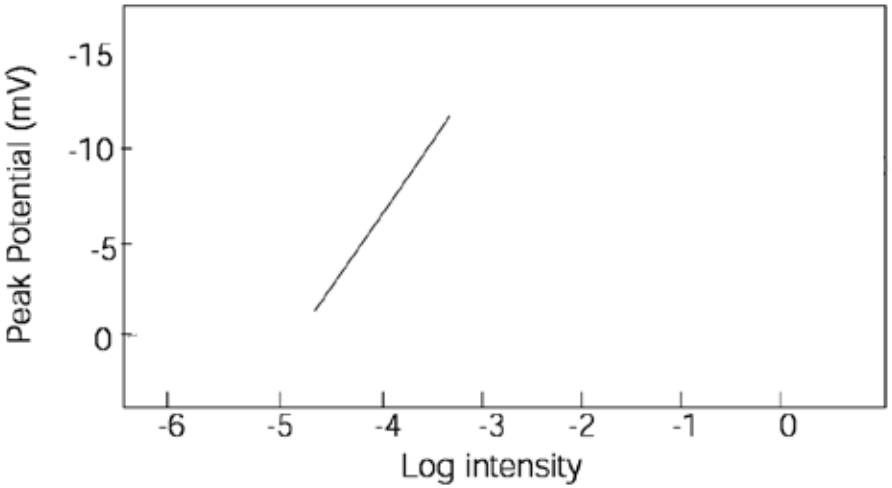
- Delbrück-type auto-adaptive pixels
  Delbrück and Mead 1994

- Custom-made VLSI retina comprising 25 pixels

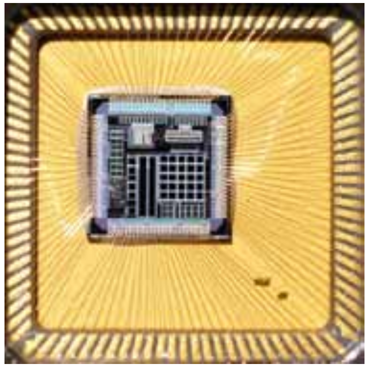
Expert, Viollet and Ruffier (2011) Journal of Field Robotics

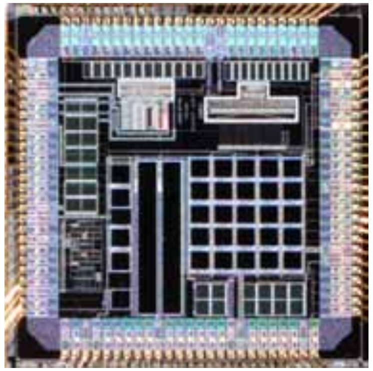
Tested sensors

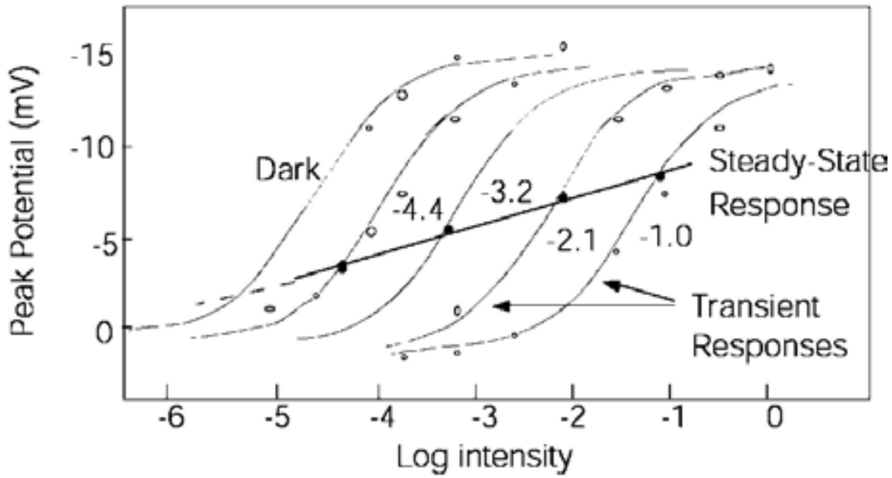
LSC : Linear array from IC-HAUS company



Adaptive Pixels for Insect-based Sensors (APIS)





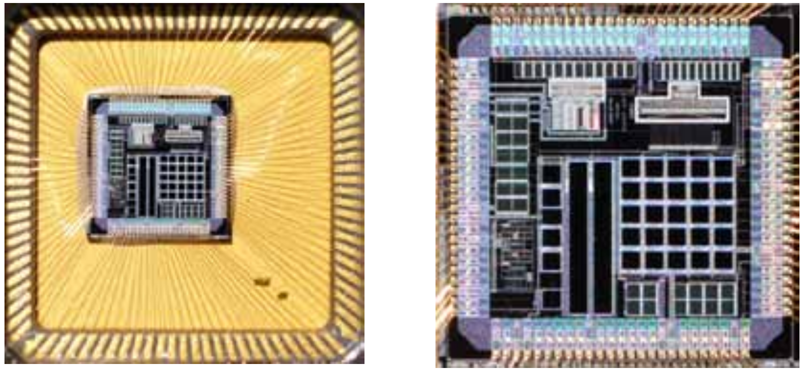


Adapted from *Normann and Perlman 1979* (on turtle retina)

Tested sensors

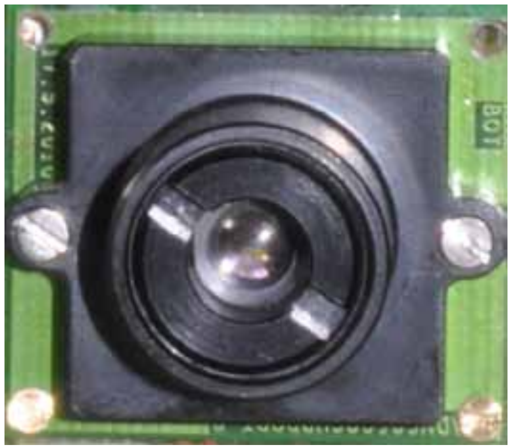
LSC : Linear array from IC-HAUS company

Adaptive Pixels for Insect-based Sensors (APIS)



Expert, Viollet and Ruffier (2011) Journal of Field Robotics

ADNS9500 – Mouse sensor



- 30x30 pixels

Expert, Viollet and Ruffier (2011) IEEE Sensors Conf.

Part 1 :

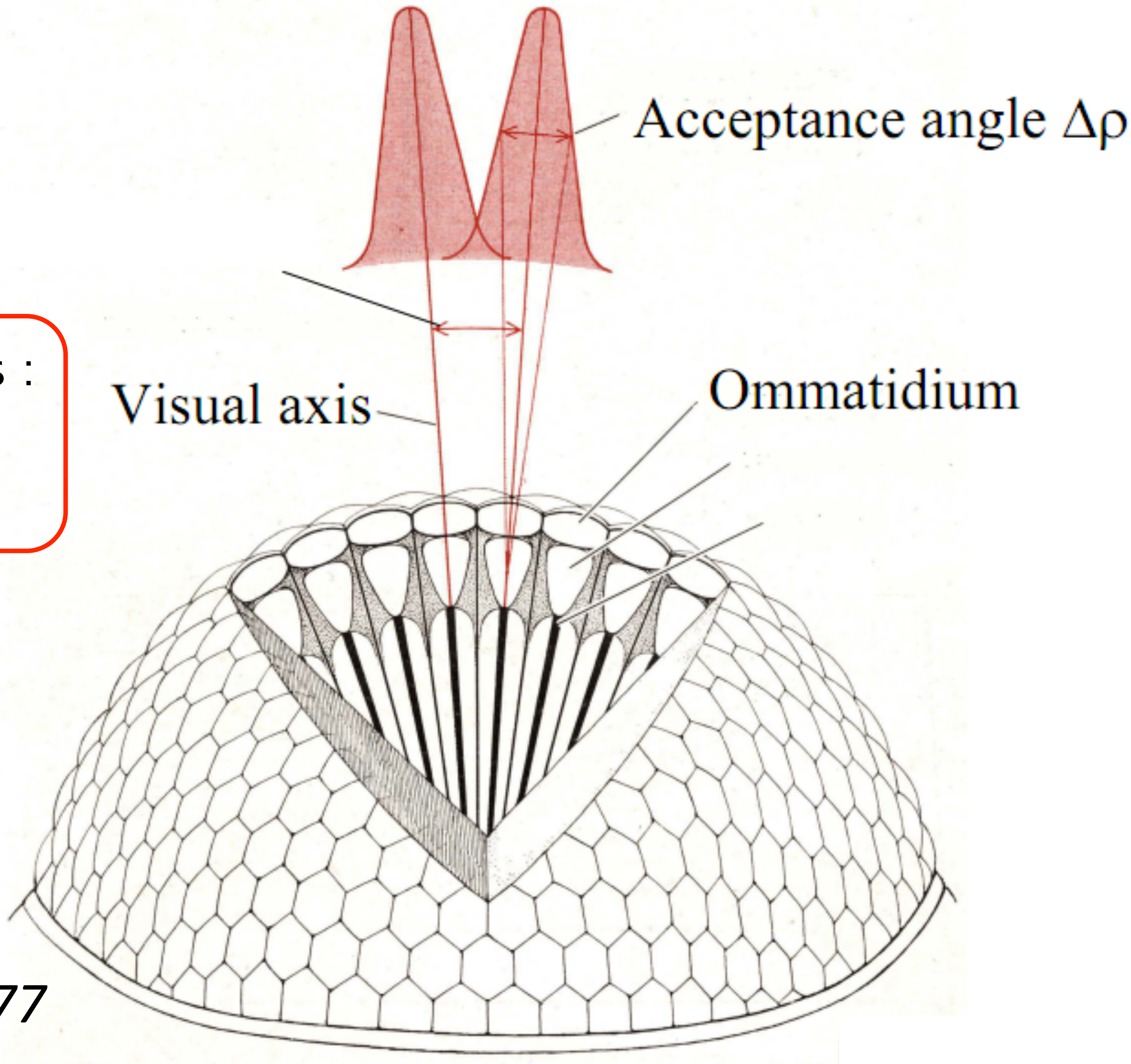
Time of travel processing and optical characterization

Elementary structure of a compound eye

Diurnal insects :

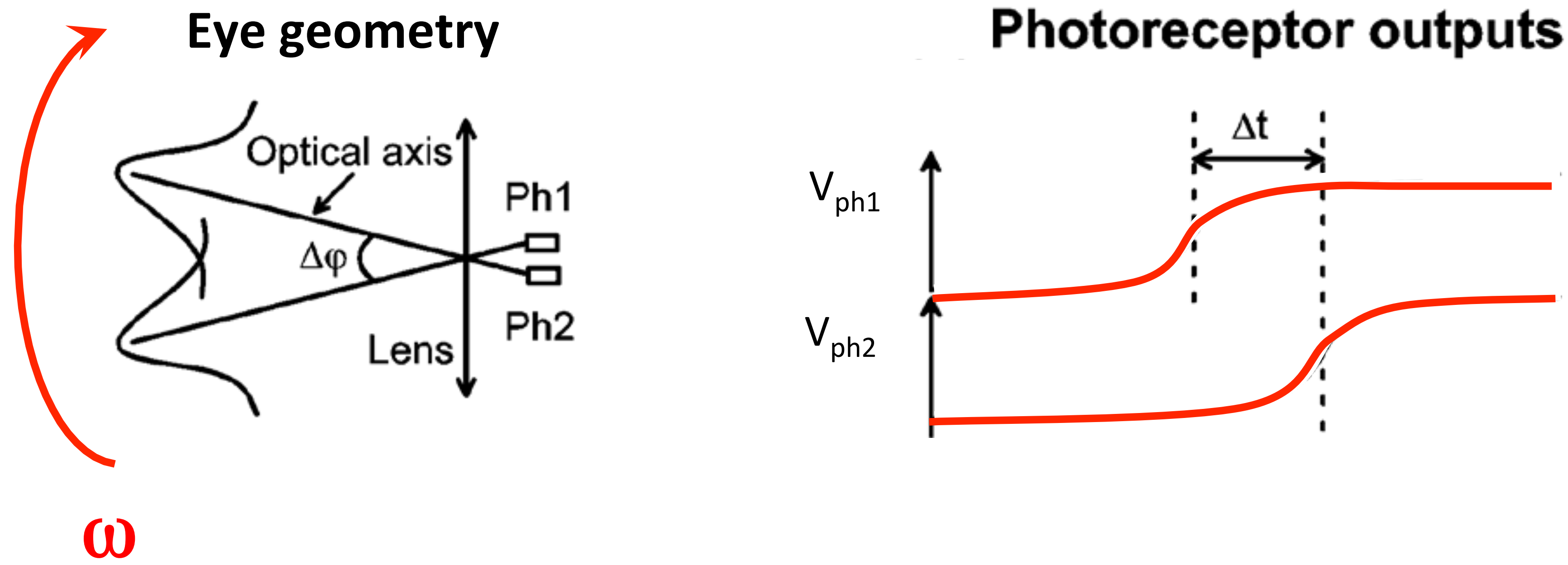
$\Delta\phi \approx \Delta\rho$

Land 1997



Horridge 1977

A fly-inspired elementary eye



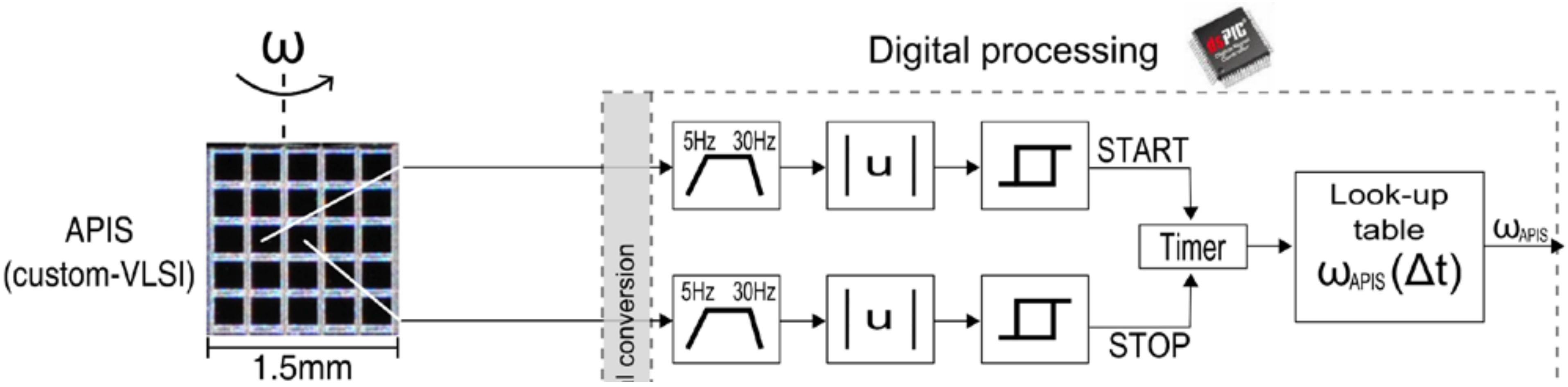
⇒ The eye optics converts the angular velocity (optic flow) ω into a delay **Δt** (“travel time” of a contrast edge)

⇒ Our EMD outputs a voltage $\omega \cong \Delta\varphi/\Delta t$

Ruffier et al. IEEE ISCAS 2003

Optic flow processing

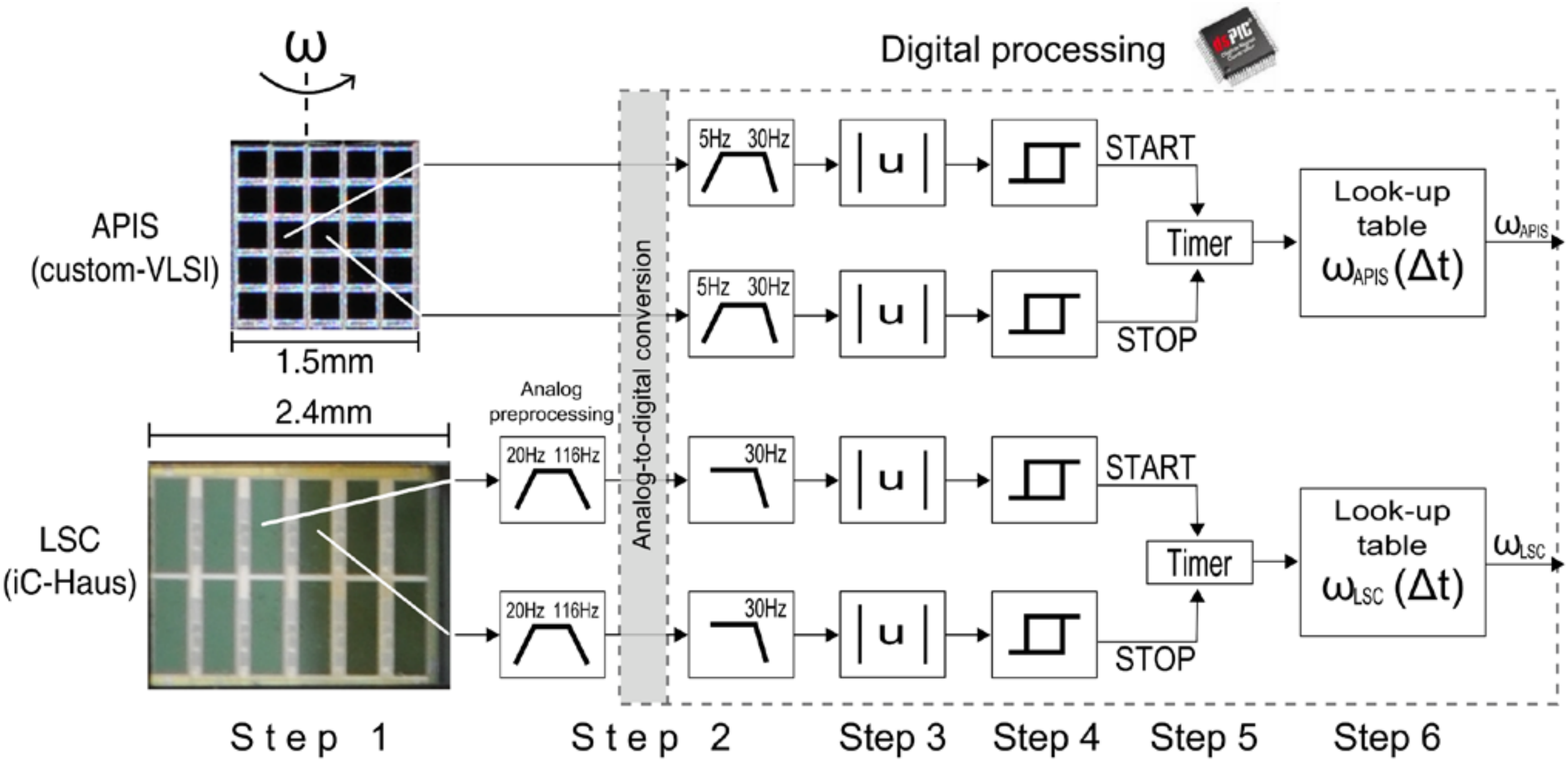
Time of travel scheme (*Blanes 86; Franceschini et al. 89, 92*)



Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Optic flow processing

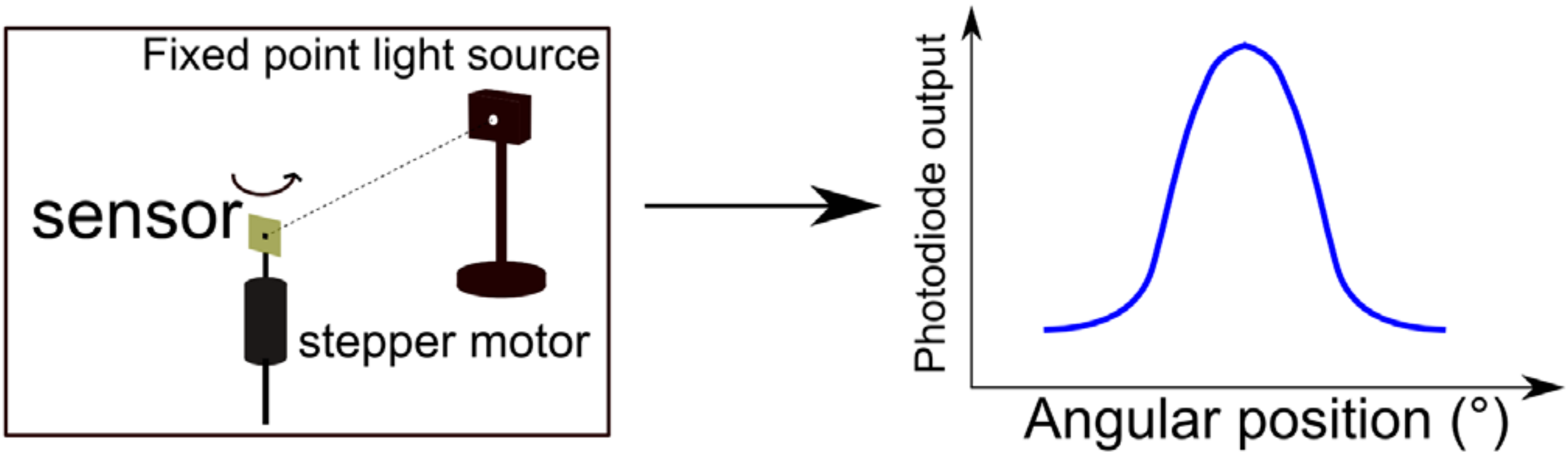
Time of travel scheme (*Blanes 86; Franceschini et al. 89, 92*)



Expert, Viollet and Ruffier (2011) Journal of Field Robotics

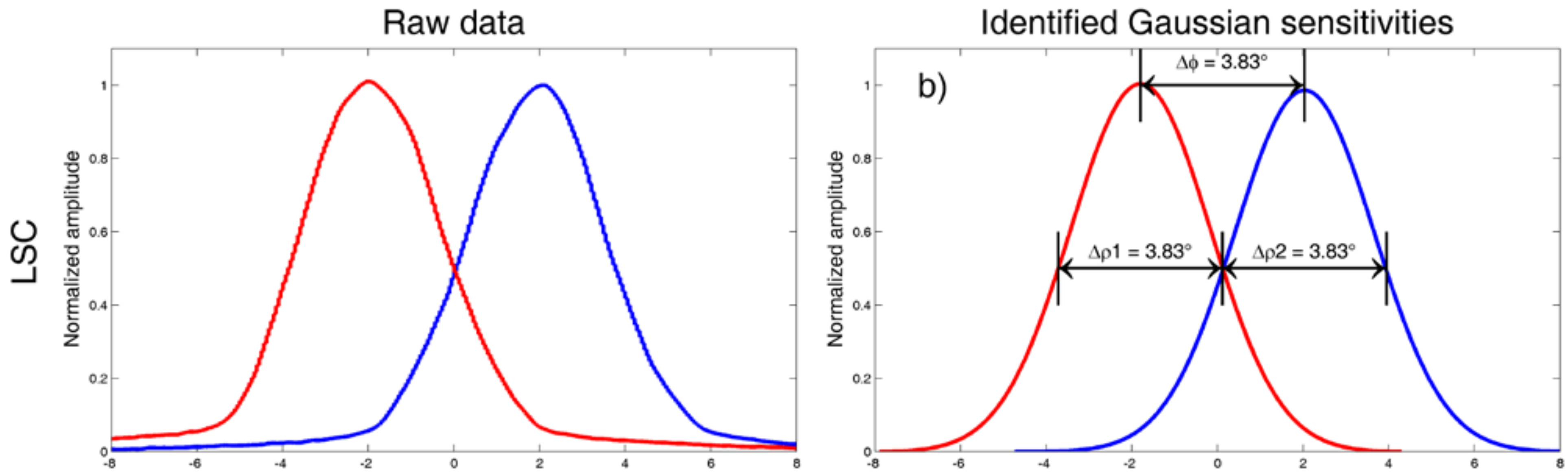
Gaussian angular sensitivity

For the LSC-based sensor, identification from a slow rotation in front of a fixed point light source.



-> Tuning Δρ by defocusing the lens

Gaussian angular sensitivity

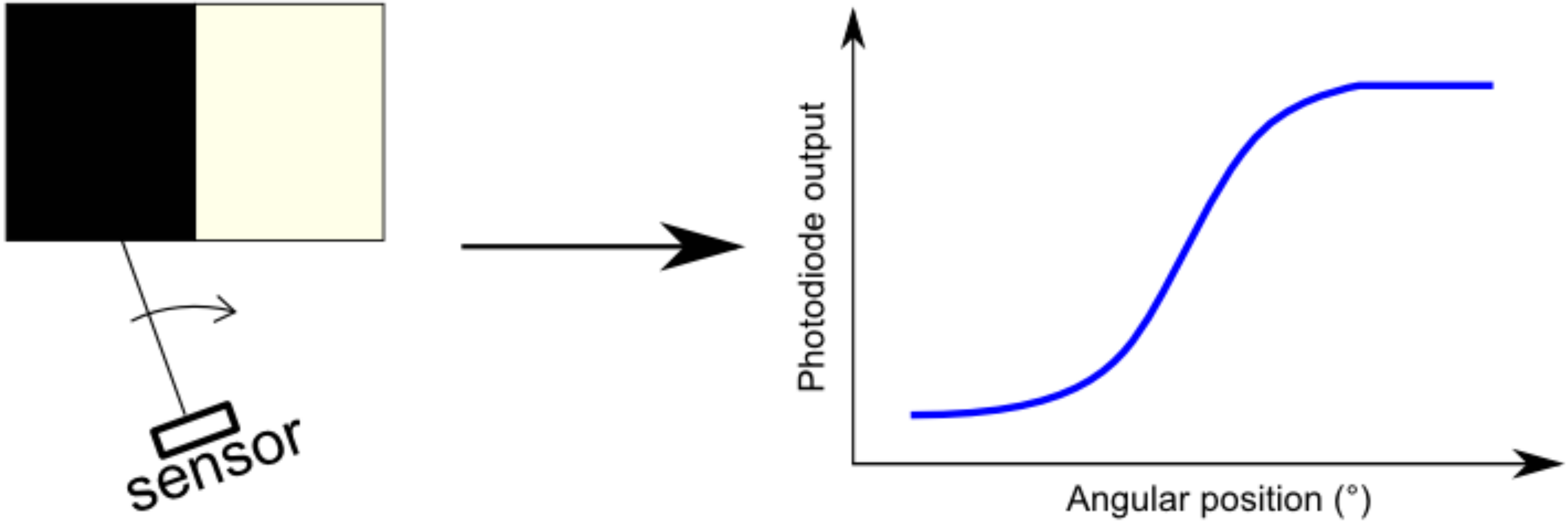


For the LSC-based sensor, identification from a slow rotation in front of a fixed point light source.

Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Gaussian angular sensitivity

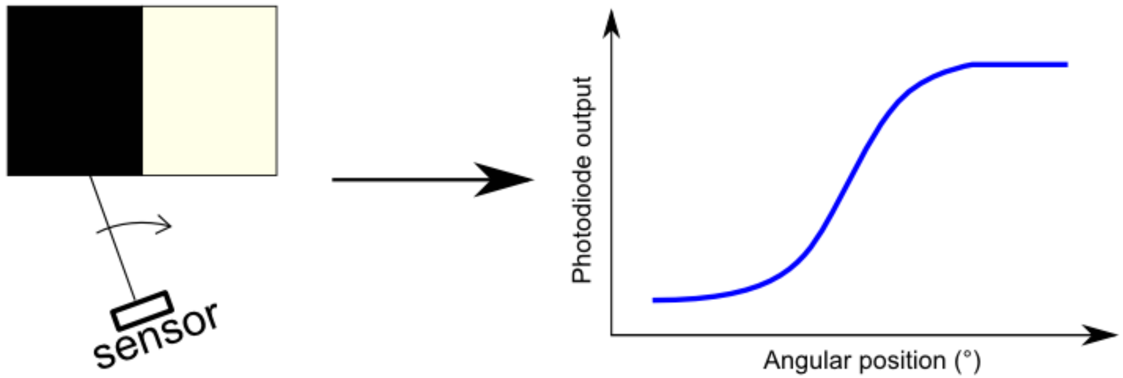
For the APIS-based sensor, identification from a rotation in front of a vertical black-and-white contrasting edge because of the temporal high-pass filter effect



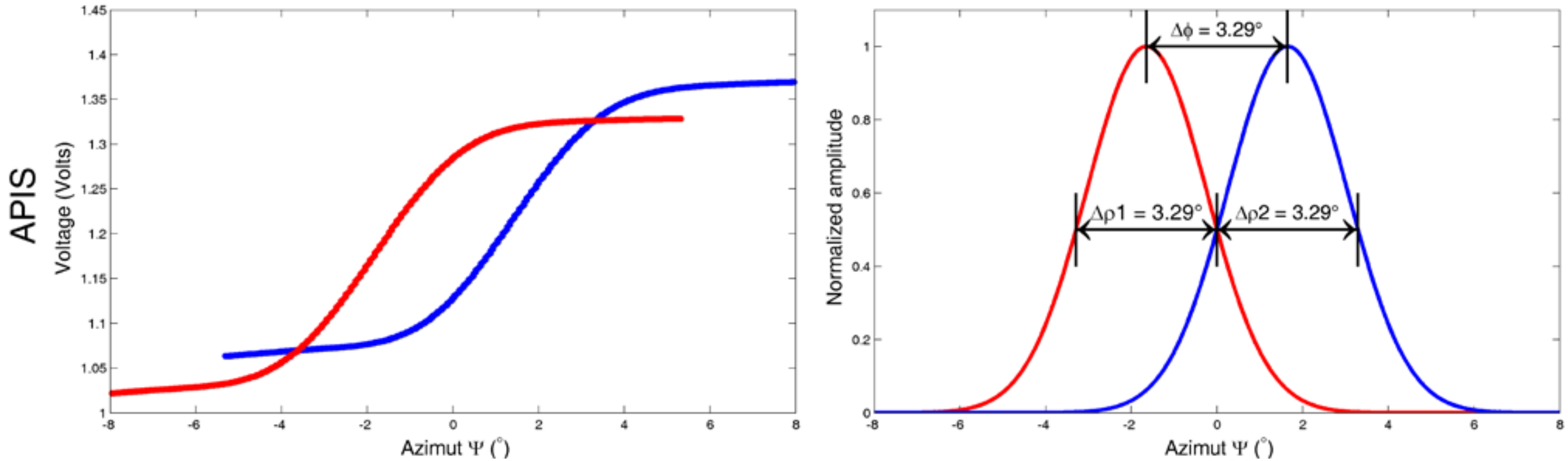
Kerhuel (2009) Phd thesis

Gaussian angular sensitivity

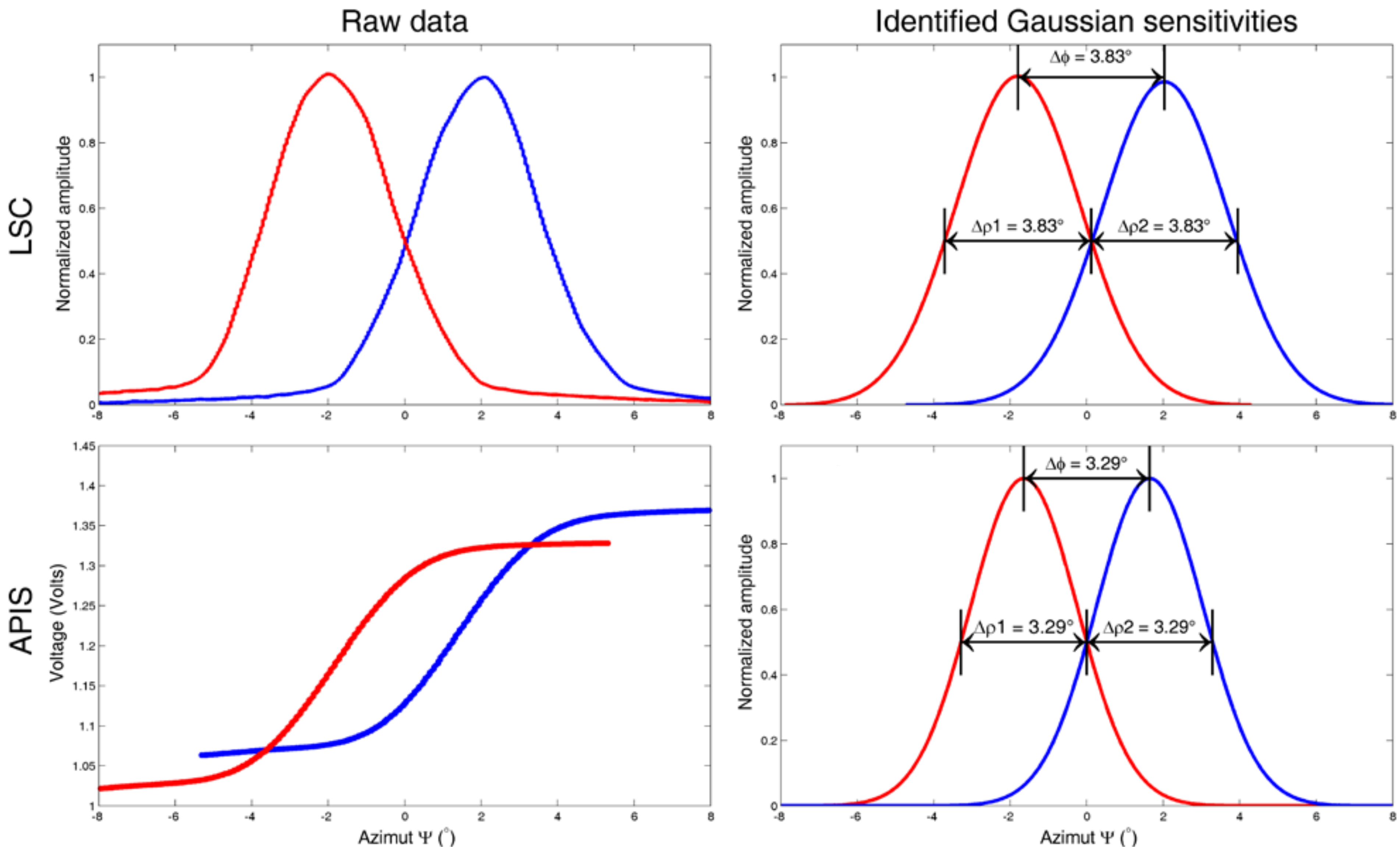
For the APIS-based sensor, identification from a rotation in front of a vertical black-and-white contrasting edge.



Kerhuel (2009) Phd thesis



Gaussian angular sensitivity

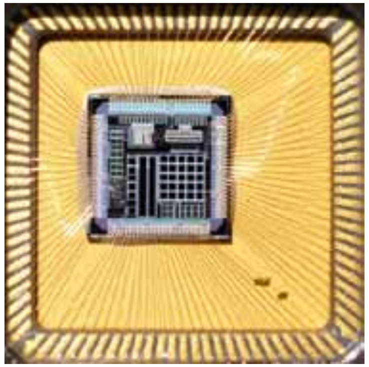


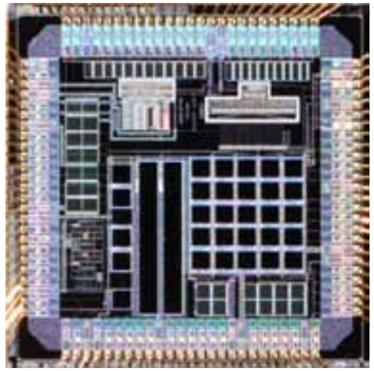
Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Part 2 : Linear pixels versus Adaptive pixels

LSC : Linear array from IC-HAUS company

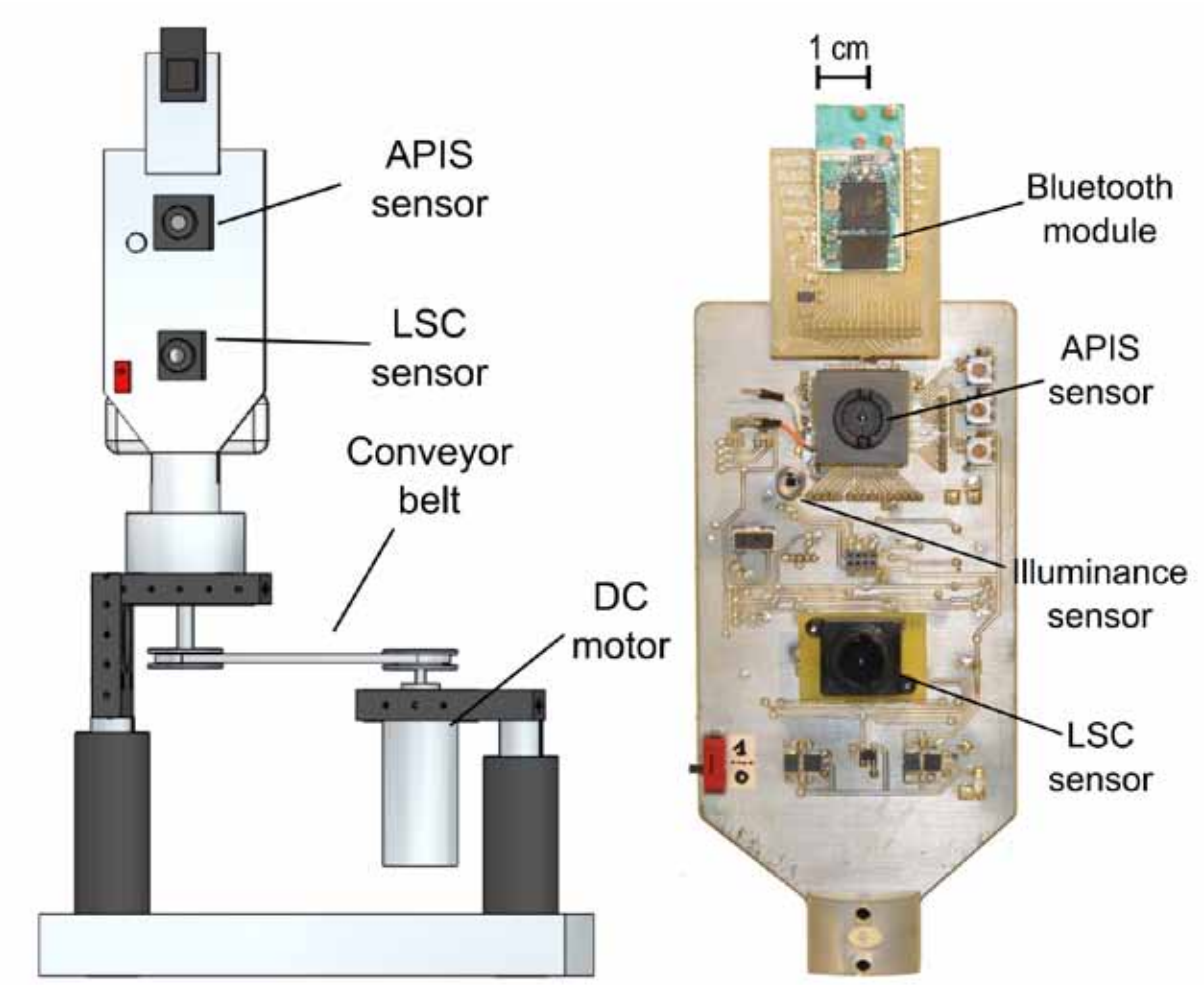
Adaptive Pixels for Insect-based Sensors (APIS)





Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Test board



-Rotational speed controlled by a PID controller

-Indoor and Outdoor experiments

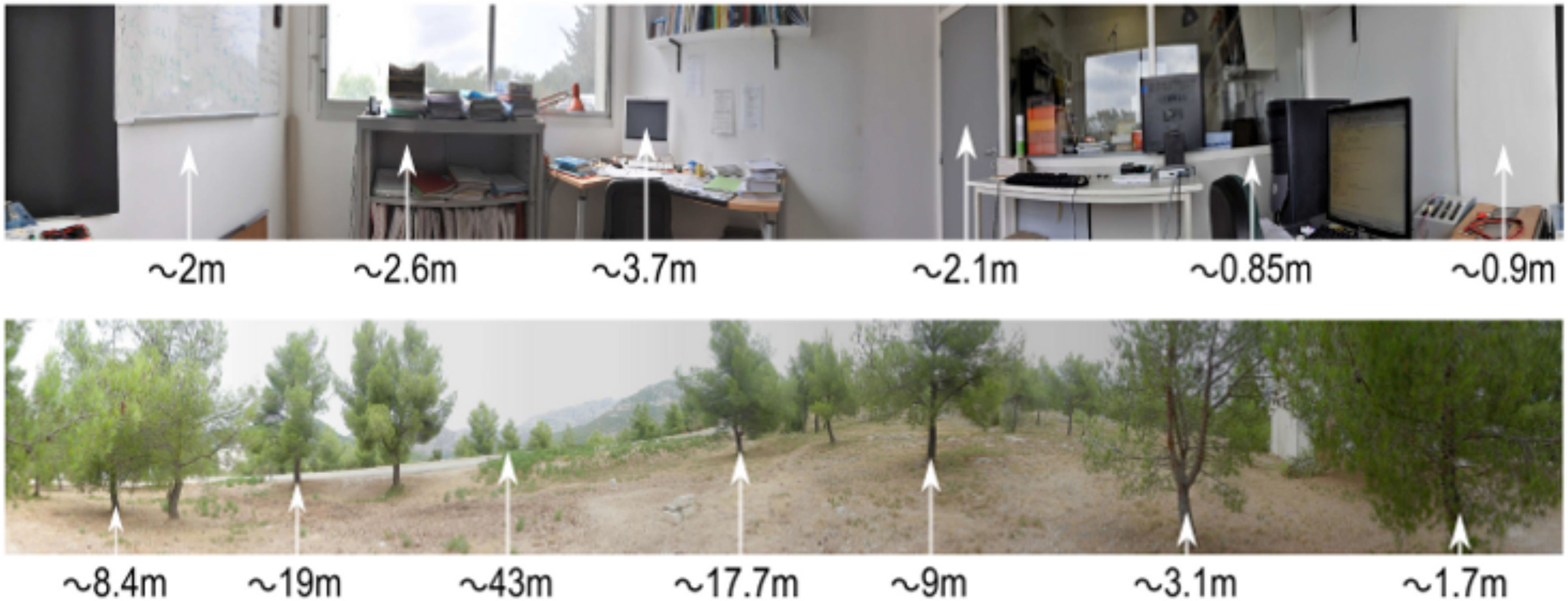
- Embedded rate gyro

- Bluetooth module

Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Real 3D scenes

Indoor and Outdoor environments.
Uncontrolled illuminance and contrasts spatial frequency and intensity.



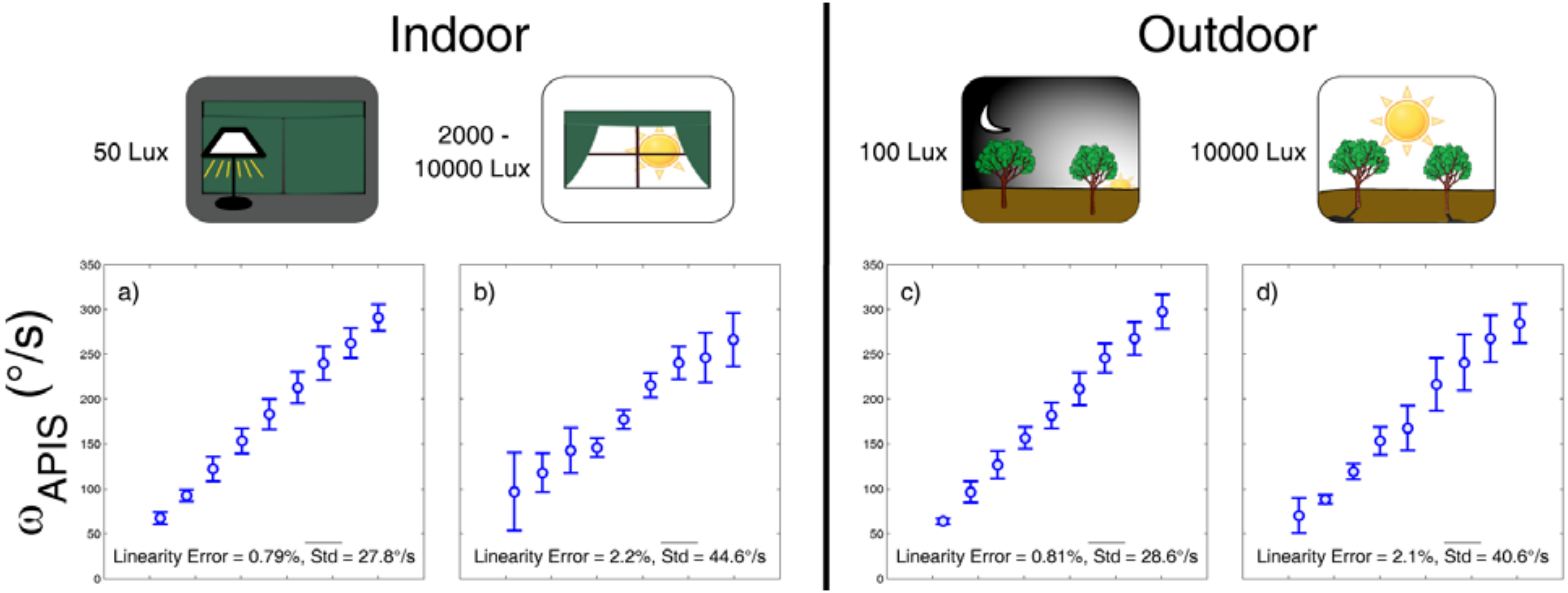
Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Static characteristics

Broad range of illuminance

Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Static characteristics

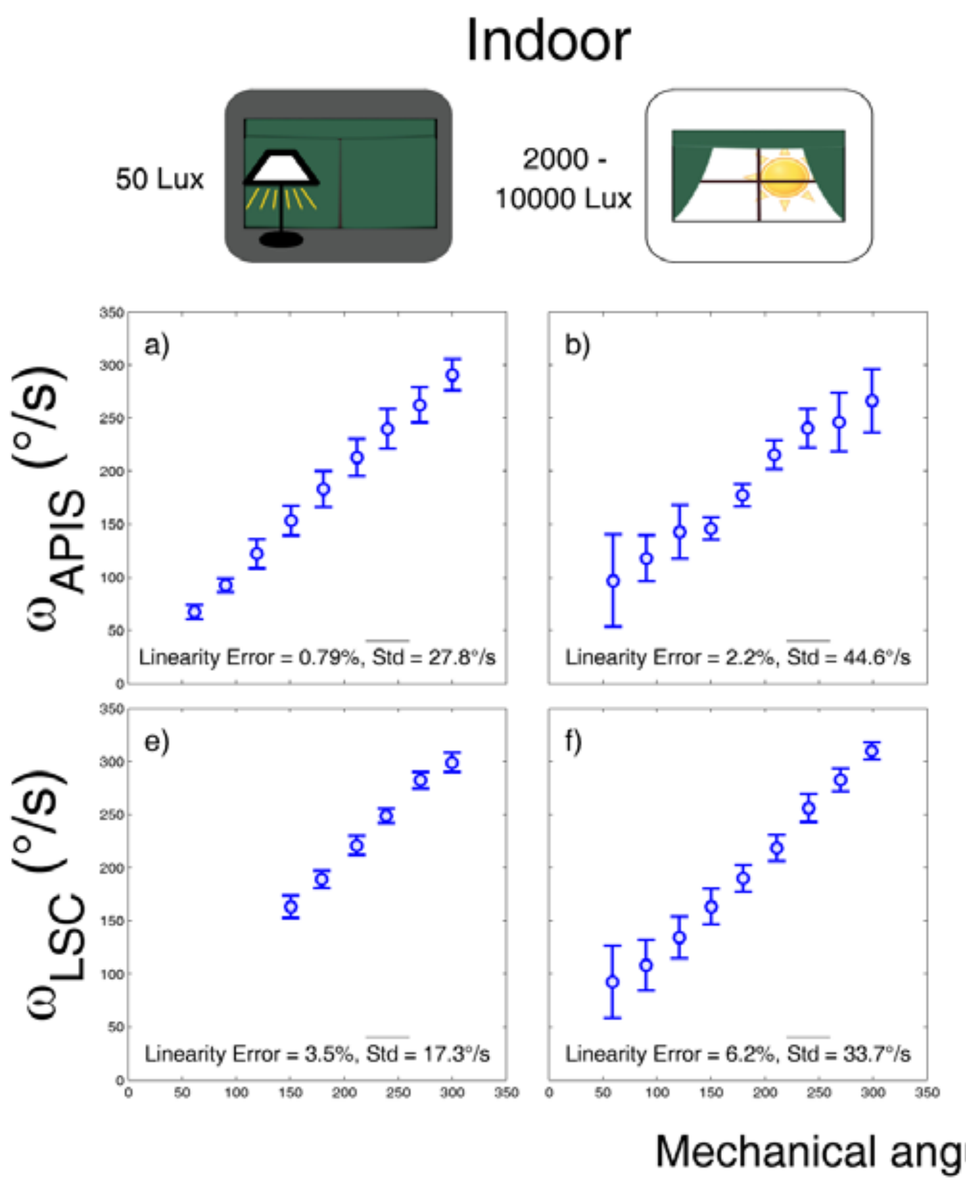


Linearity Error < 2.2%

The dispersion of the APIS-based sensor increased with the illuminance.

Expert, Viollet and Ruffier (2011) Journal of Field Robotics

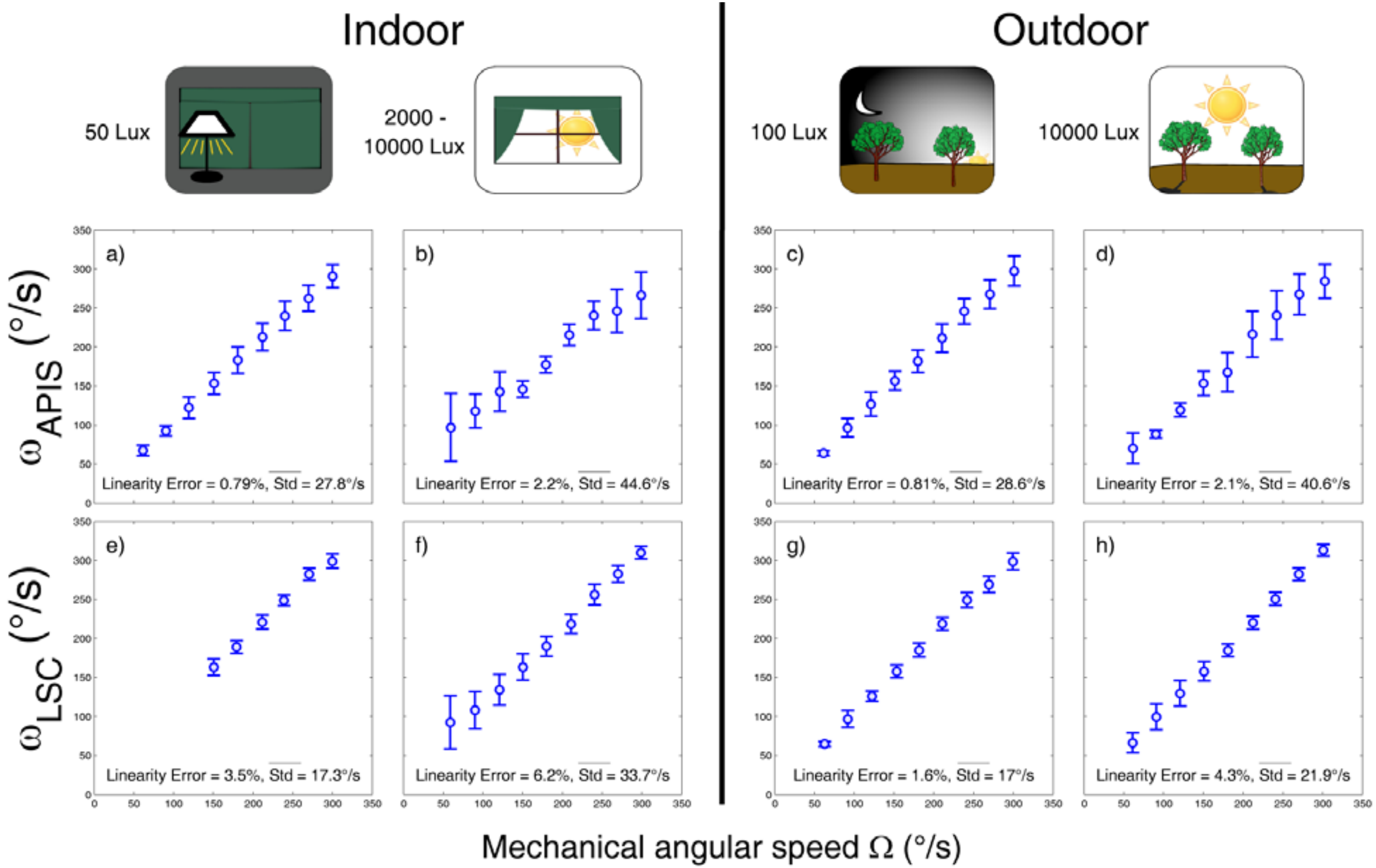
Static characteristics



The LSC-based sensor can not detect contrasts at low illuminance.
Linearity of about 5%
Dispersion < 35°/s

Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Static characteristics



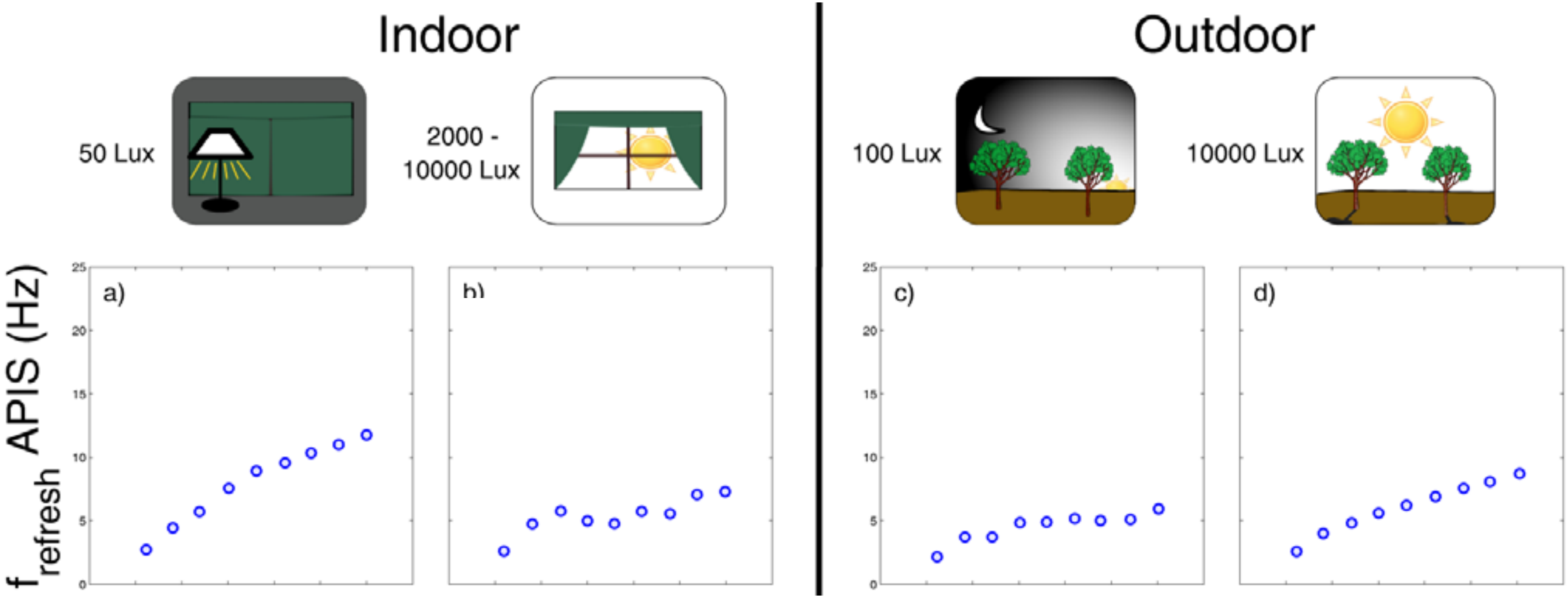
Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Refresh rate analysis

Refresh rate = number of new measurements per second with a time lag between the two pixels detection belonging to our measurement range [50°/s, 350°/s]

Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Refresh rate analysis- APIS



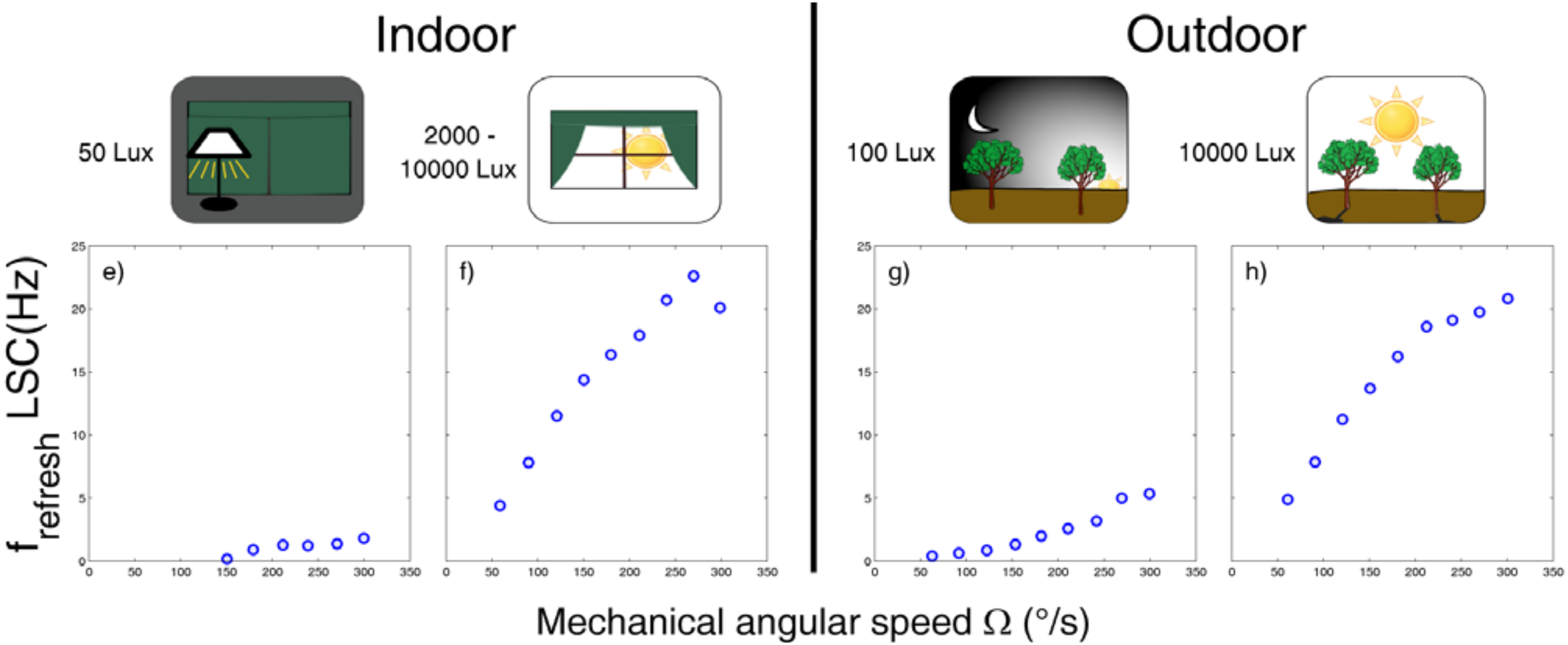
APIS-based sensor refresh rate independant of the illuminance.

Do not increase linearly with the angular speed due to the strong variations in the background illuminance.

The APIS chip is therefore constantly adapting to a new illuminance with a relatively slow time constant.

Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Refresh rate analysis - LSC



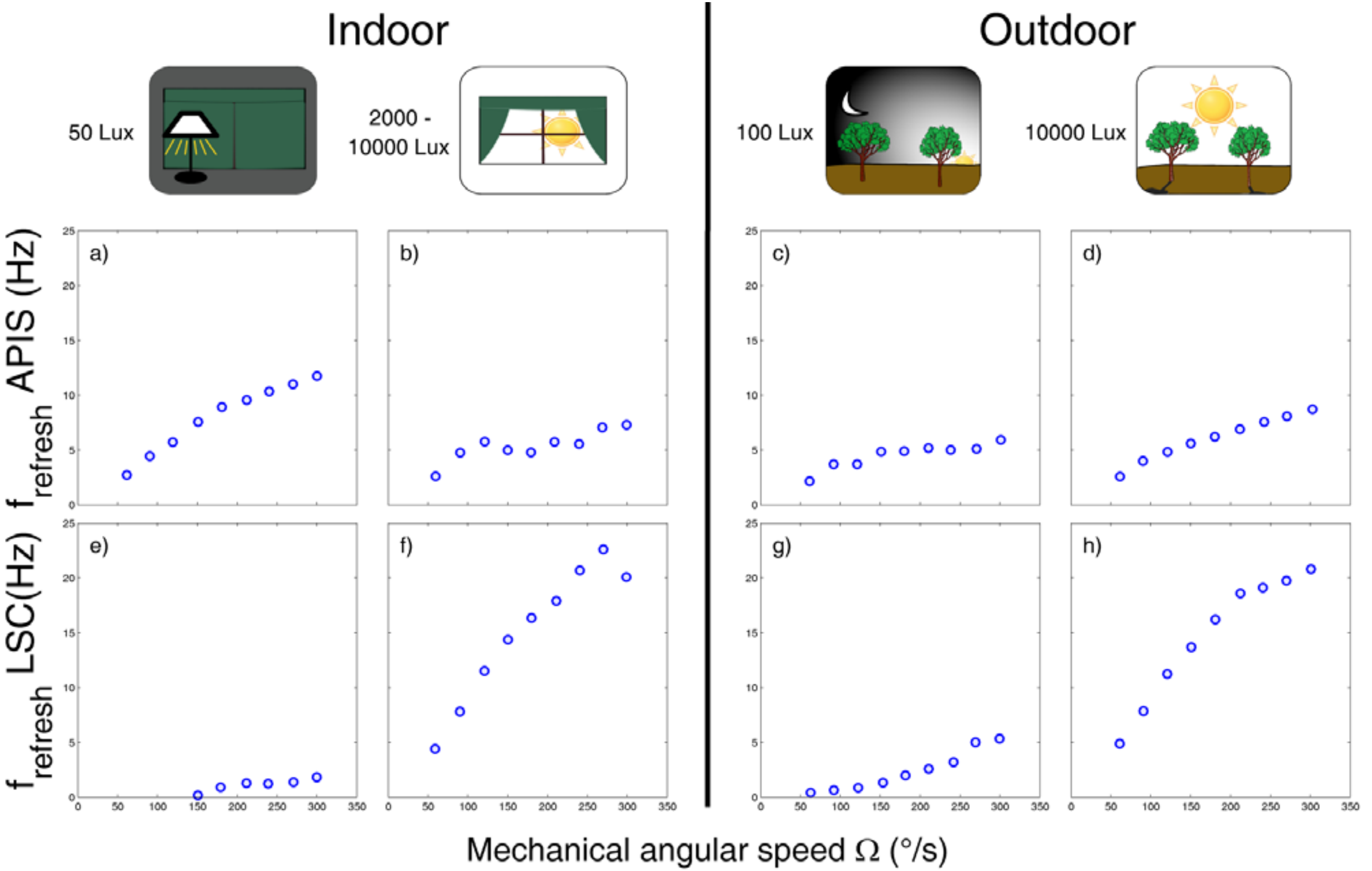
Strong refresh rate variations with the illuminance.

Linear increase of the number of new measurements with the angular speed for the LSC-based sensor.

Saturation at high angular speeds due to the low-pass filters.

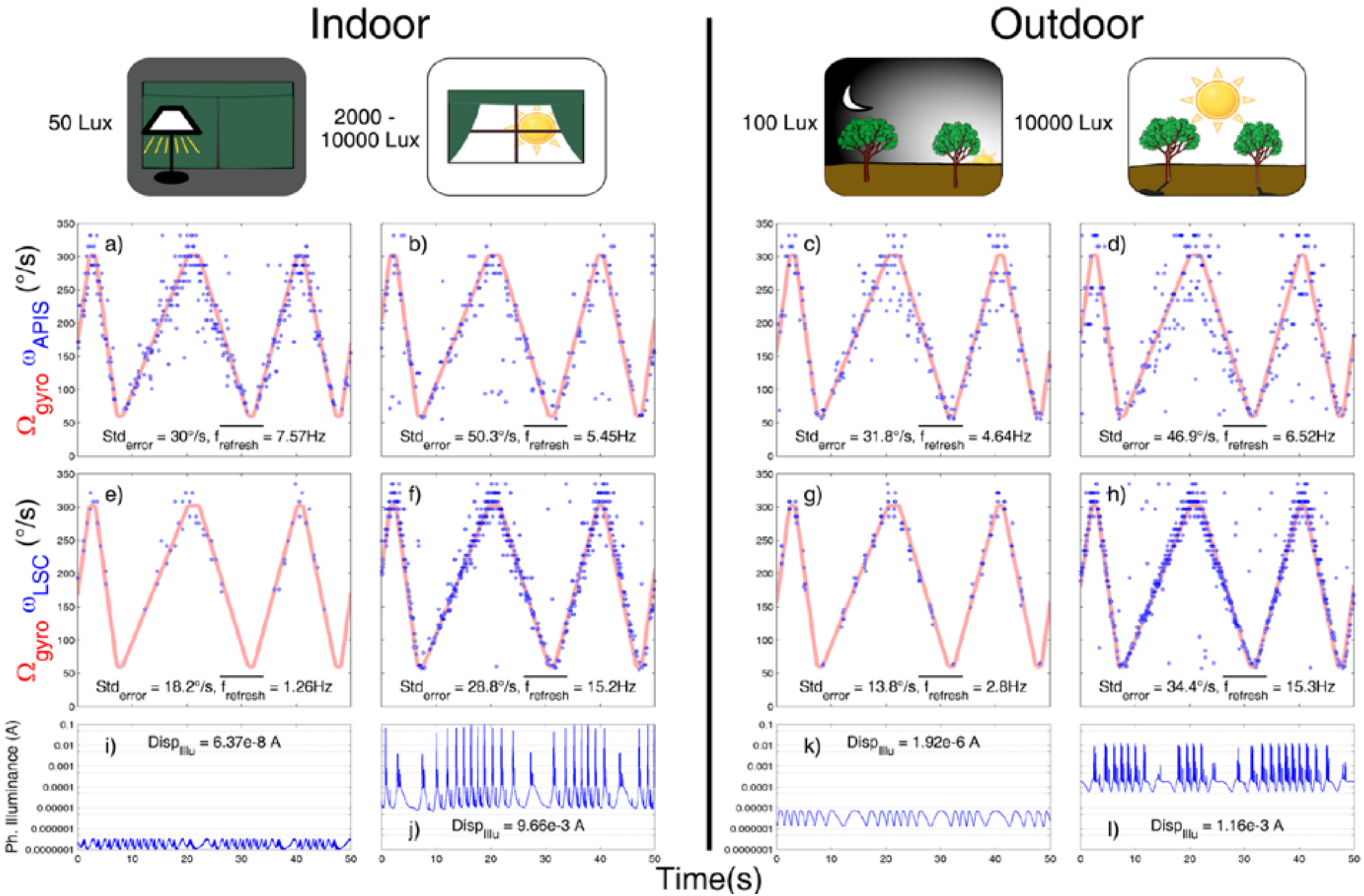
Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Refresh rate analysis



Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Dynamic characteristics



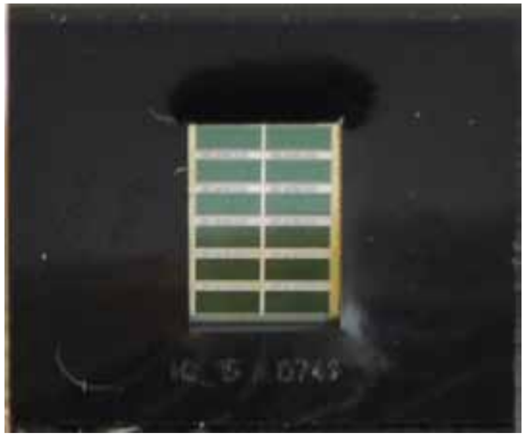
Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Conclusion of Part 2

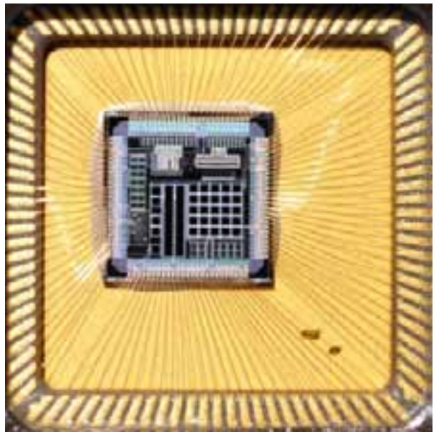
-> LSC-based sensor can provide 1 angular speed measurement in a narrow illuminance range (1.5 decades).

-> APIS-based sensor can provide 1 angular speed measurement in a 3-decade range (independant of the illuminance).

LSC



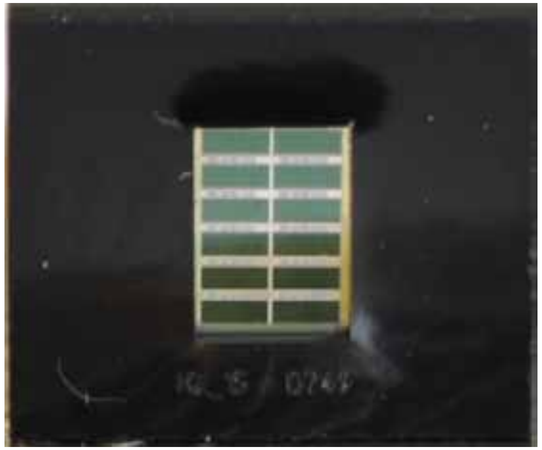
APIS



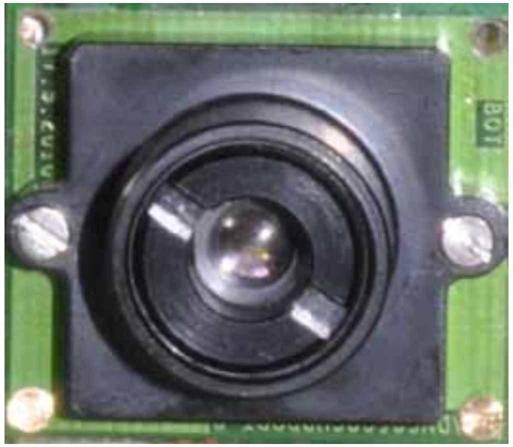
Expert, Viollet and Ruffier (2011) Journal of Field Robotics

Part 3 : Time of travel processing versus Mouse sensor

LSC : Linear array from
IC-HAUS company

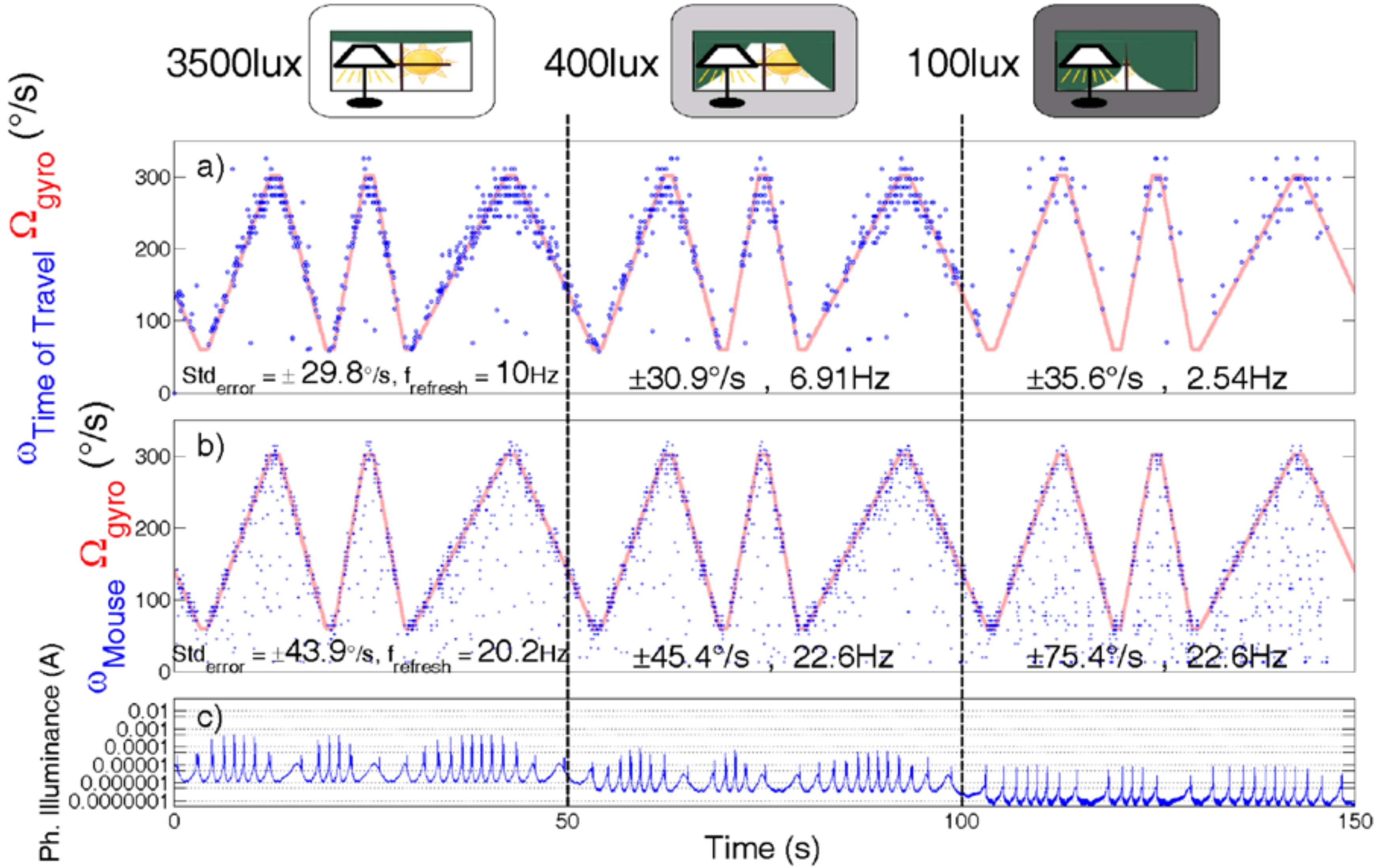


Mouse sensor



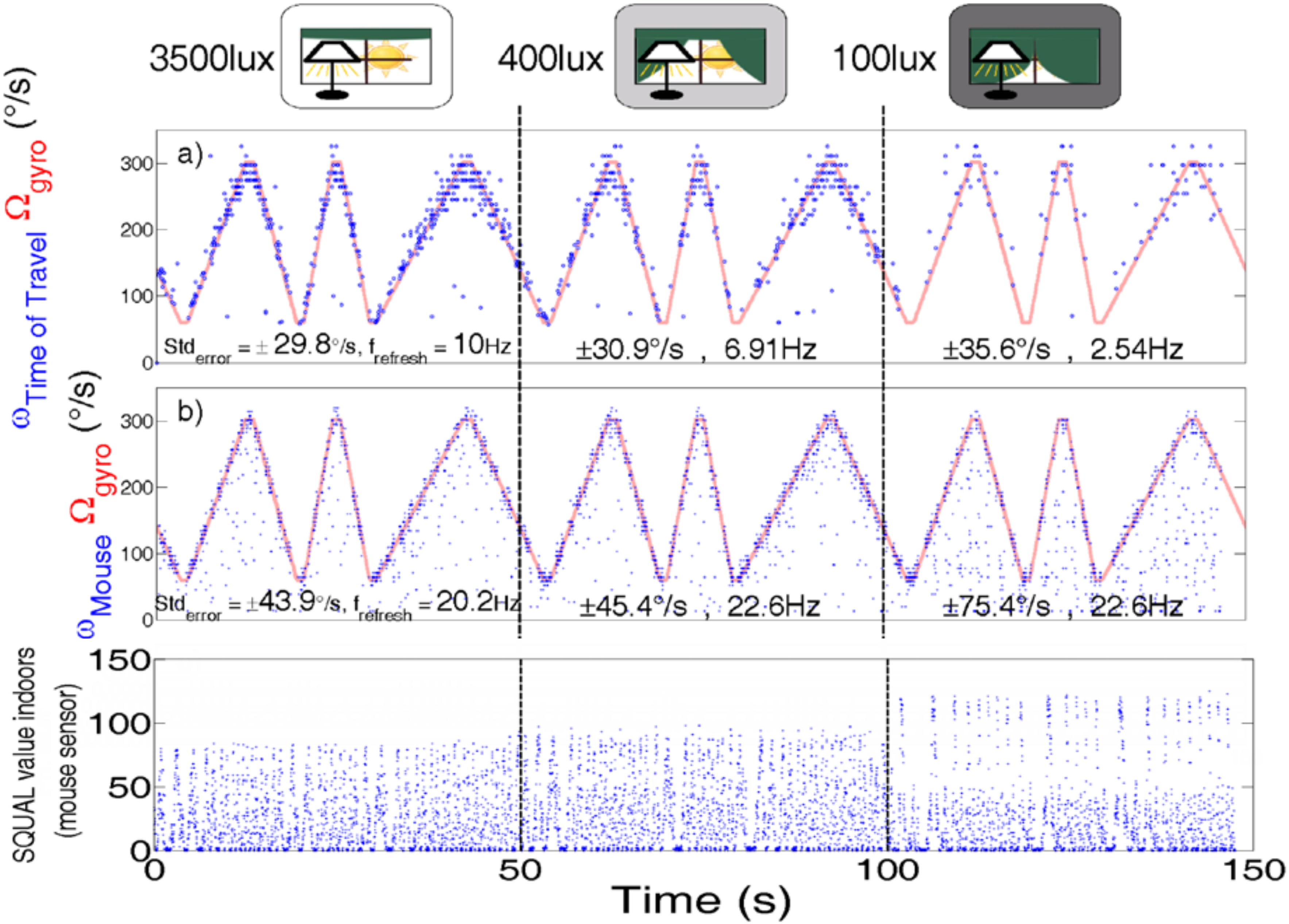
Expert, Viollet and Ruffier (2011) IEEE-Sensors Conf. 2011

Dynamic characteristics



Expert, Viollet and Ruffier (2011) IEEE-Sensors Conf. 2011

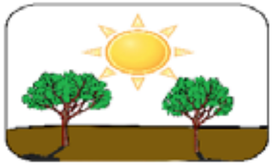
Dynamic characteristics

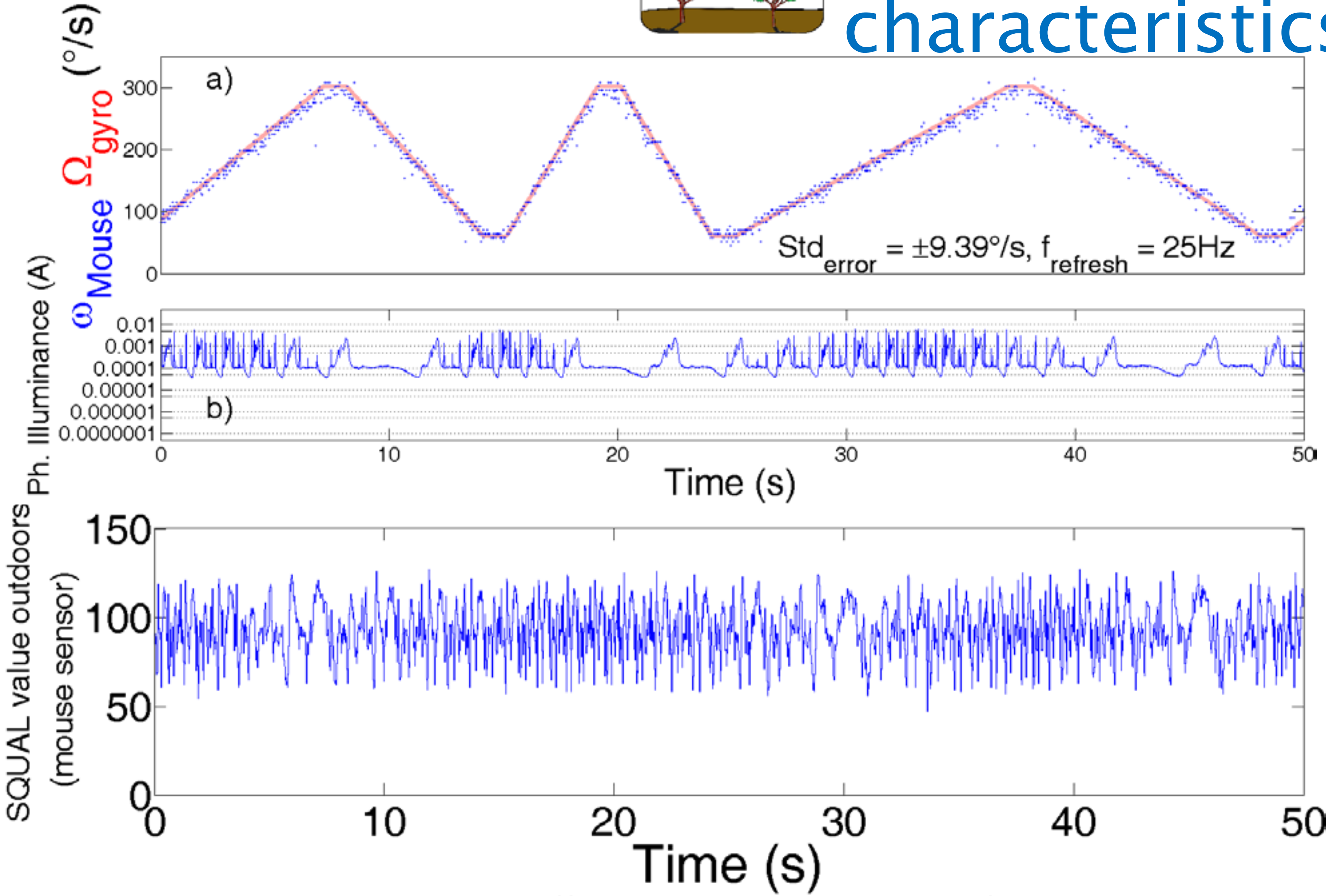


Expert, Viollet and Ruffier (2011) IEEE-Sensors Conf. 2011

Dynamic characteristics

10000 lux





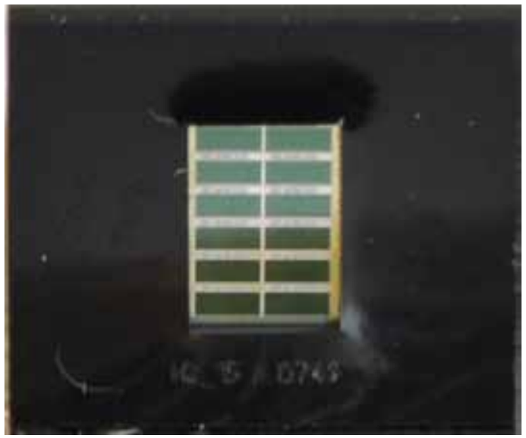
Expert, Viollet and Ruffier (2011) IEEE-Sensors Conf. 2011

Conclusion of Part 3

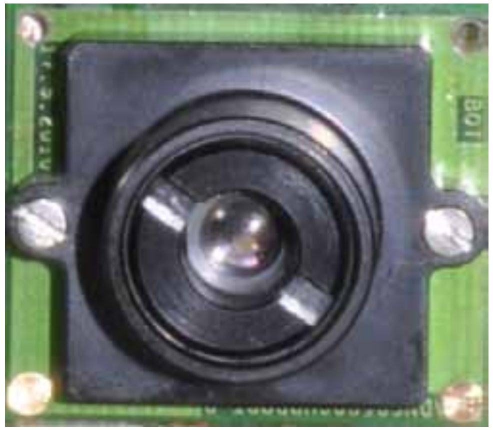
-> LSC-based sensor can provide 1 angular speed measurement in a narrow illuminance range (1.5 decades).

-> Mouse sensor can provide 2 angular speed (x-y) measurement with a better refreshed output 25Hz (high illuminance).

LSC



Mouse sensor



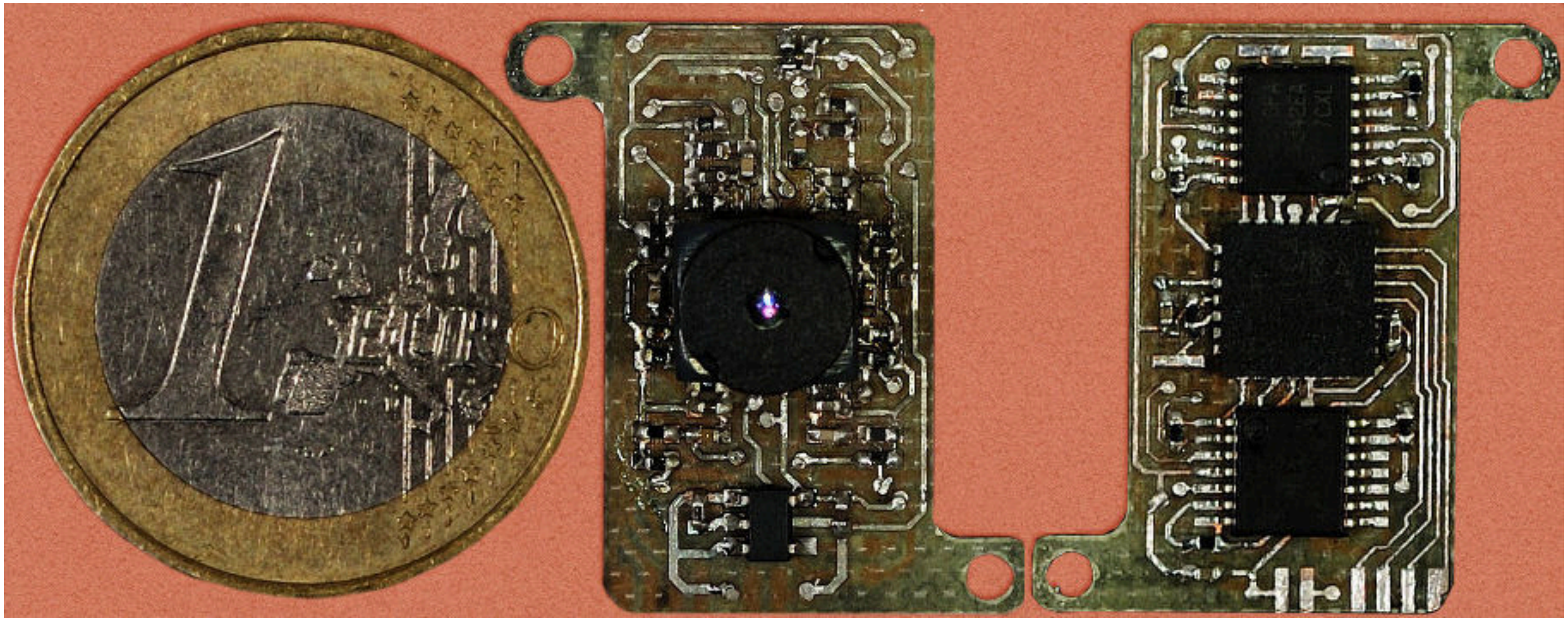
Expert, Viollet and Ruffier (2011) IEEE-Sensors Conf. 2011

Part 4 : Stand alone 1-gram device of the visual motion sensor

-> 5 single 1-D angular speed measurements, ω ∈ [25°/s; 350°/s]

-> 1 fused output : median of the 5 single measurements

-> Size, mass and power-consumption reduced

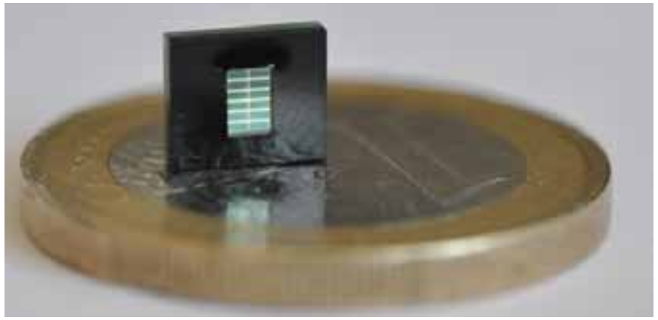


Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

IEEE Sensors 2011: Best Student Paper Award « 1st prize »

Lens/photodiode assembly

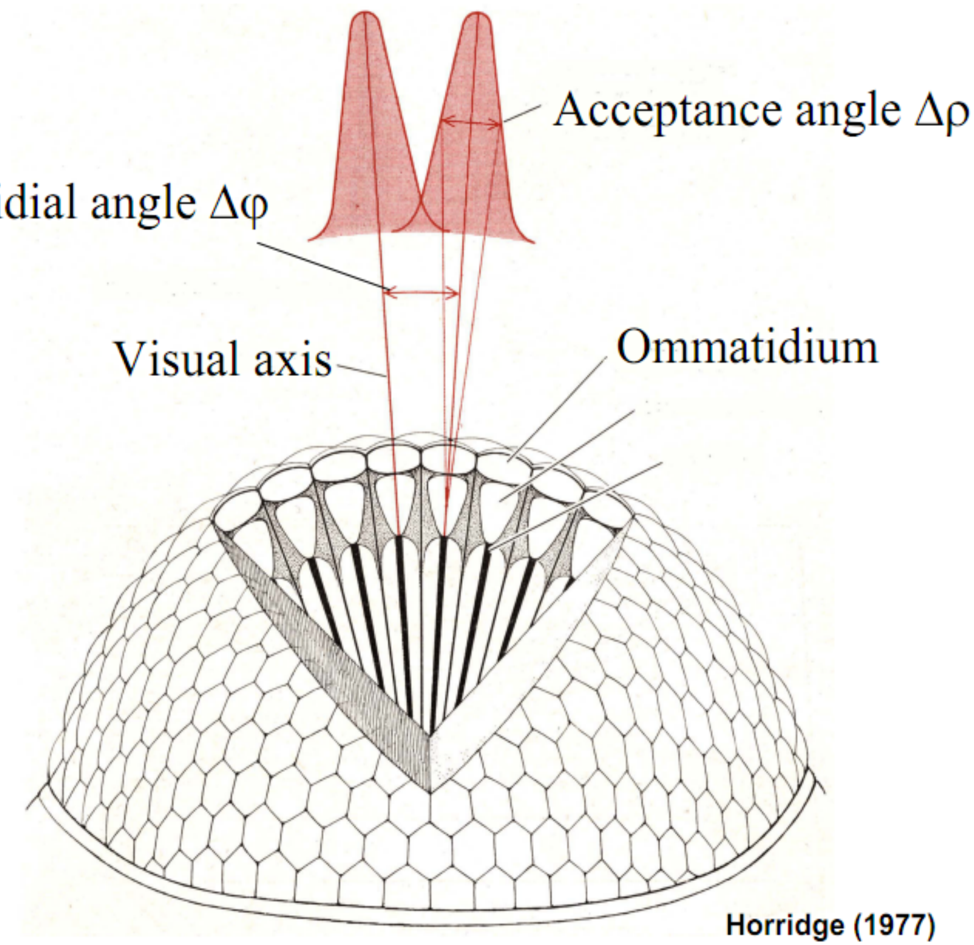
Linear array of 6 photodiodes



- Linear on-chip current preamplification circuit

Lens from *Sparkfun*™

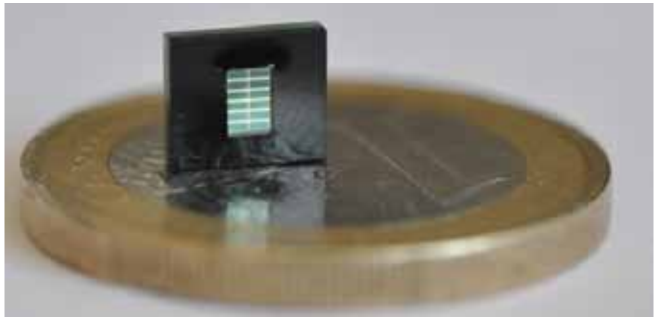
- Focal length 2mm
- f-number 2.8



Horridge (1977)

Lens/photodiode assembly

Linear array of 6 photodiodes

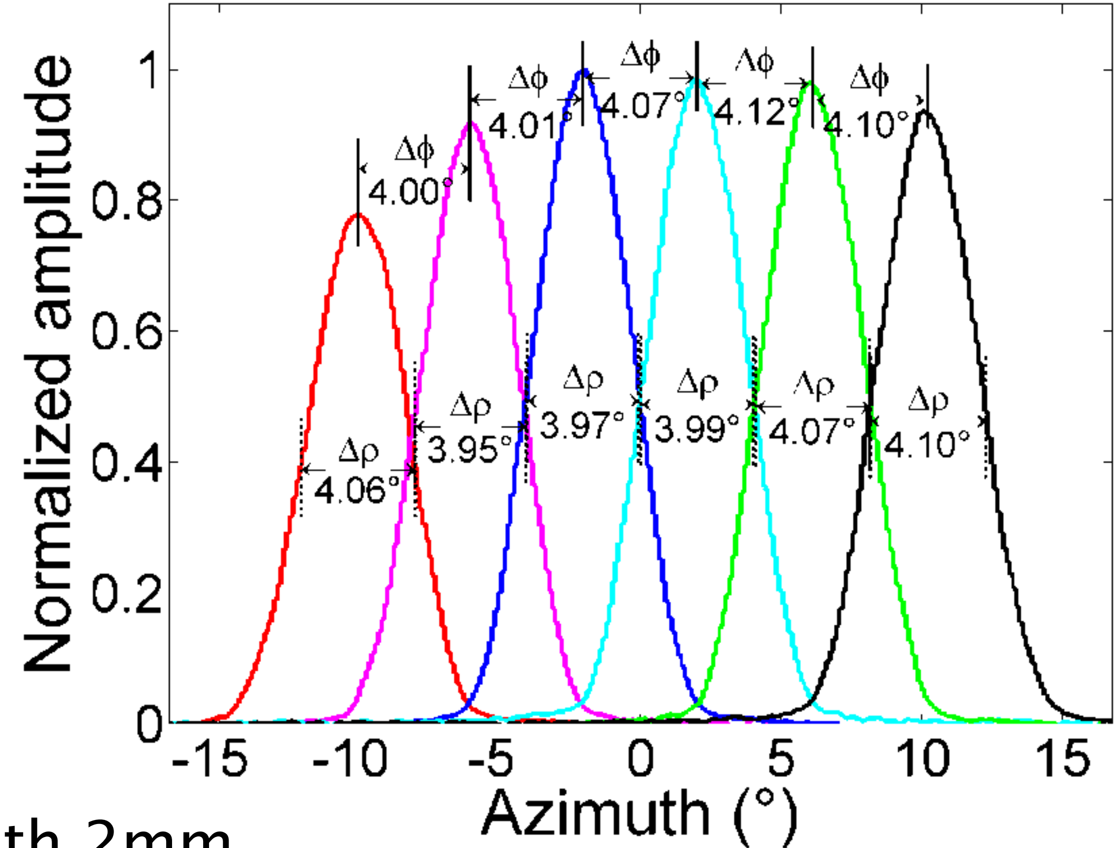


- Linear on-chip current preamplification circuit

Lens from *Sparkfun™*

- Focal length 2mm
- f-number 2.8

Gaussian angular sensitivities

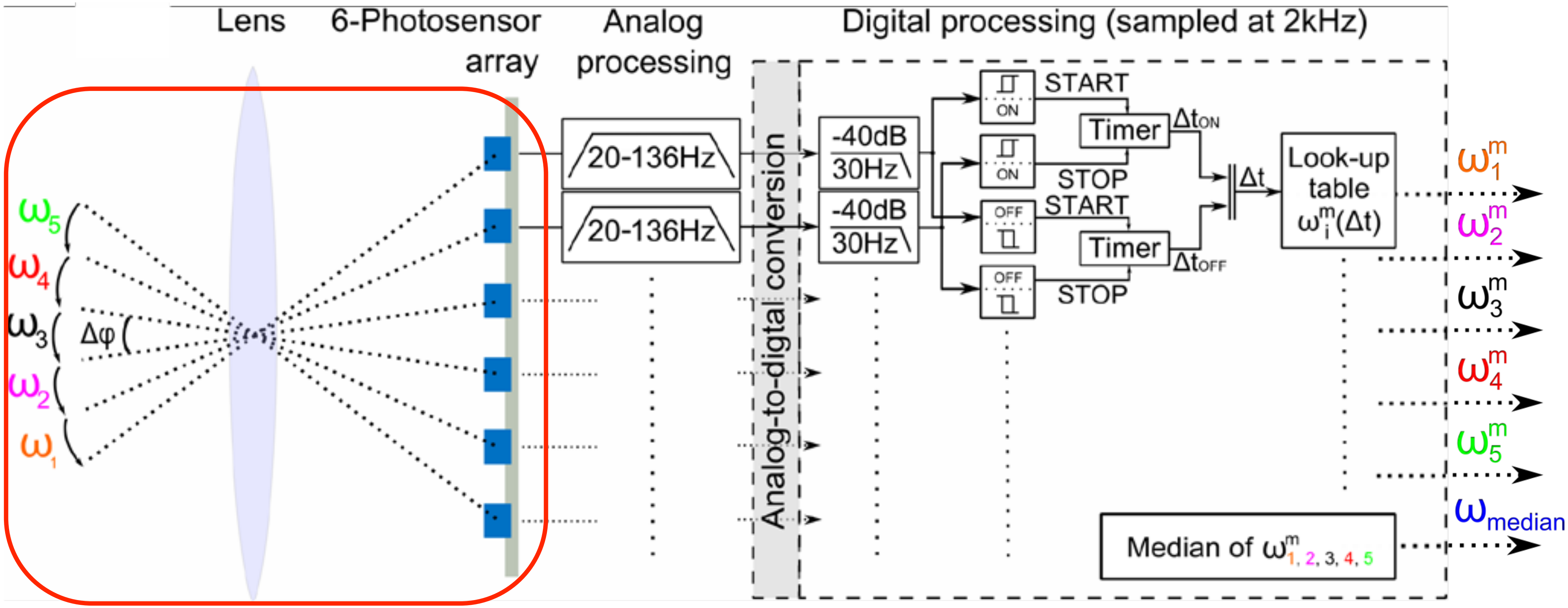


Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Optic flow processing

Time of travel scheme (*Blanes 86; Franceschini et al. 89, 92*):

6 processing steps

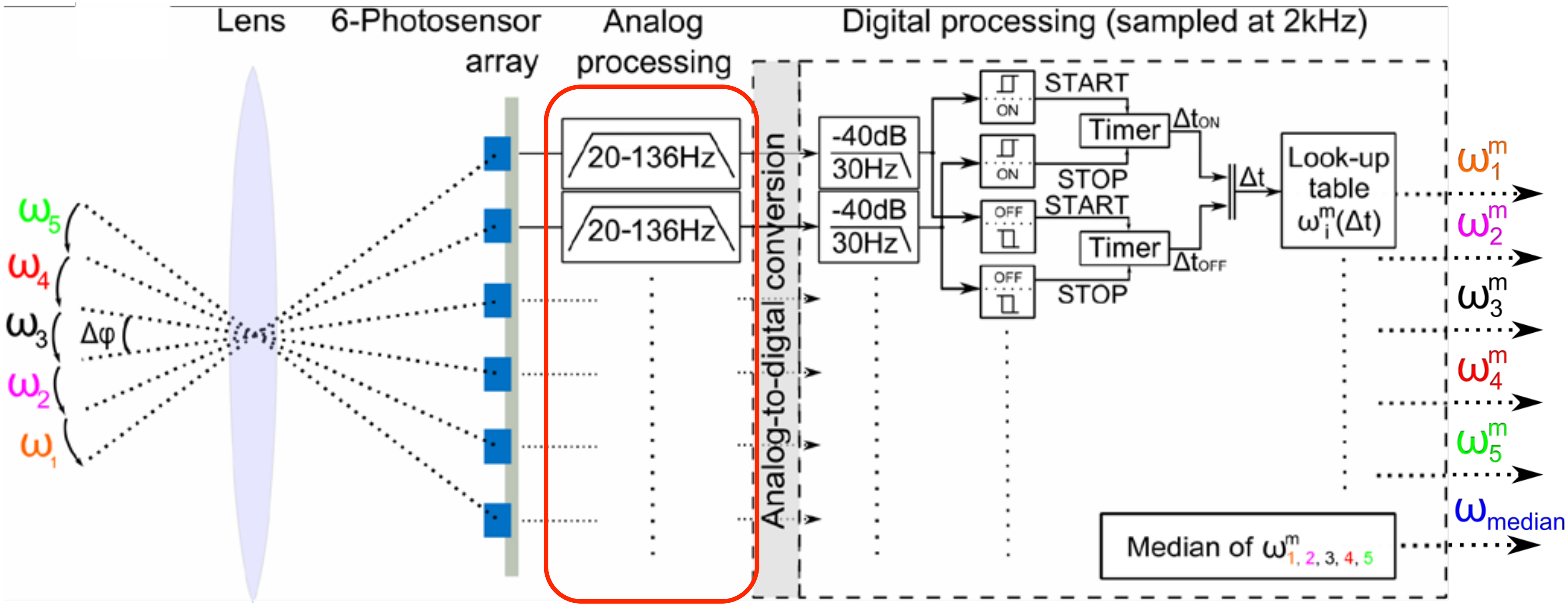


Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Optic flow processing

Time of travel scheme (*Blanes 86; Franceschini et al. 89, 92*):

6 processing steps

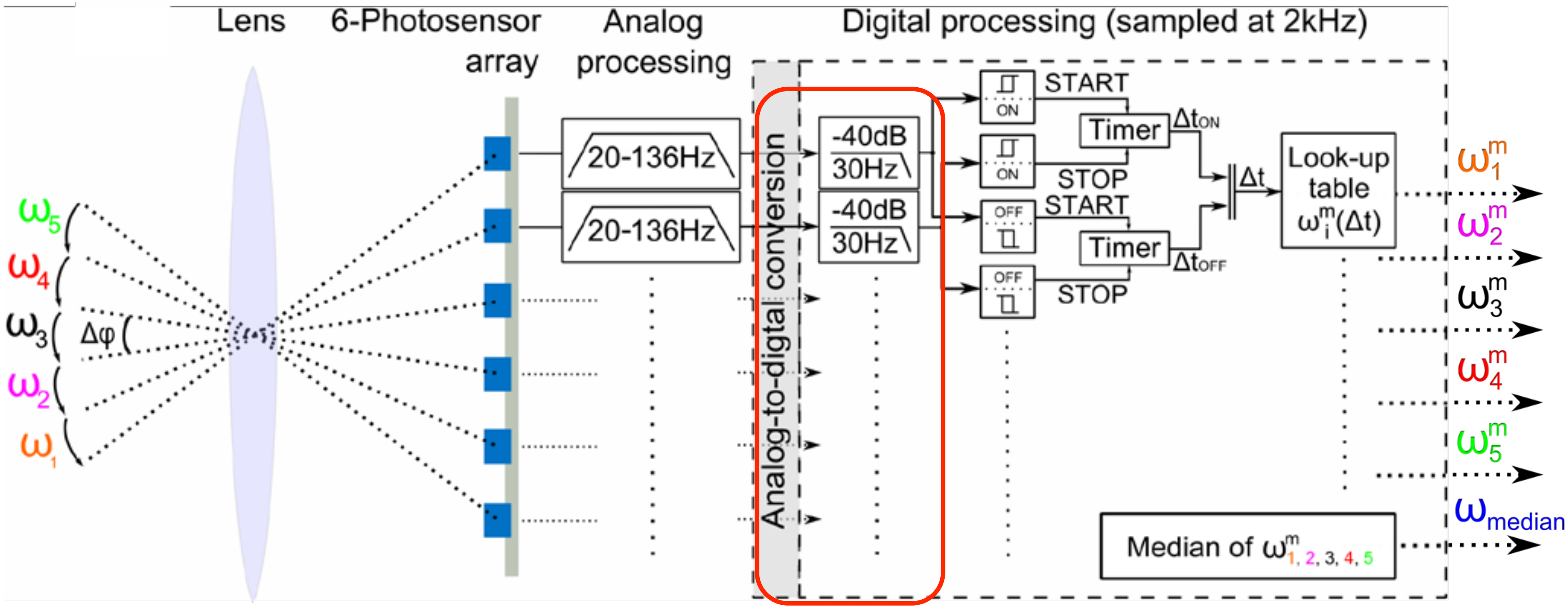


Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Optic flow processing

Time of travel scheme (*Blanes 86; Franceschini et al. 89, 92*):

6 processing steps

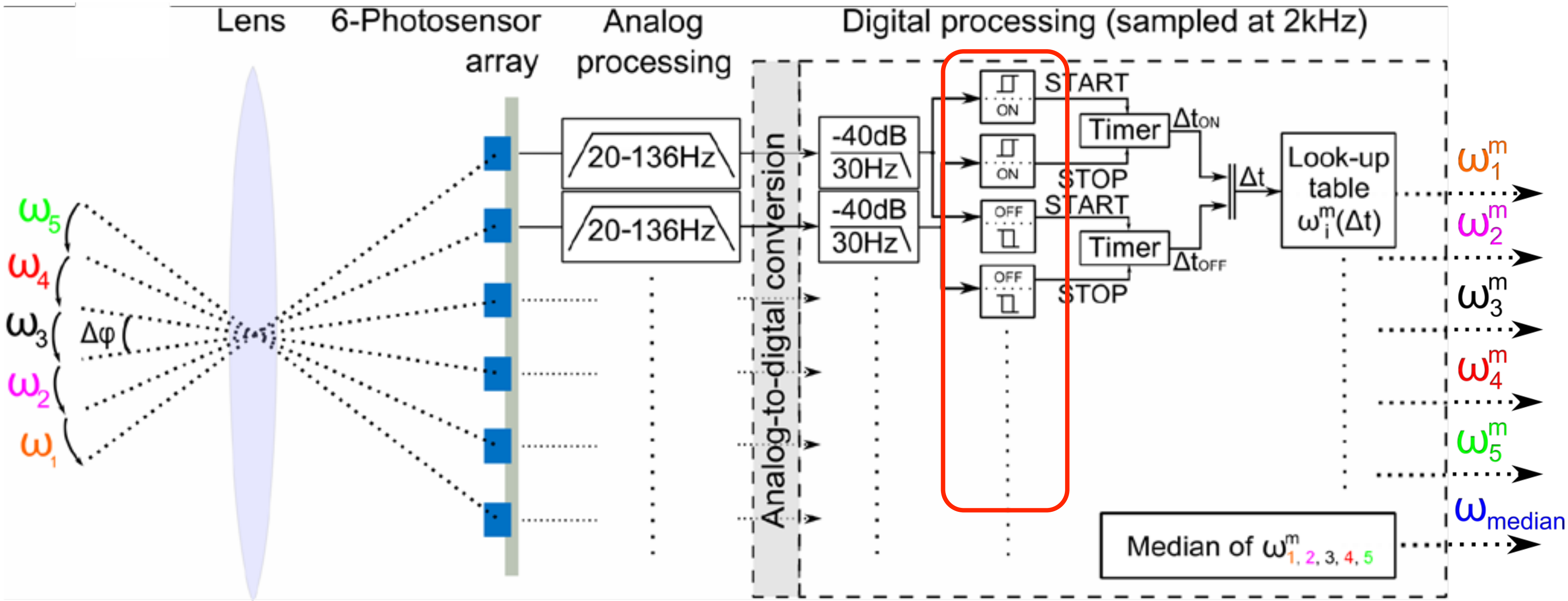


Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Optic flow processing

Time of travel scheme (*Blanes 86; Franceschini et al. 89, 92*):

6 processing steps

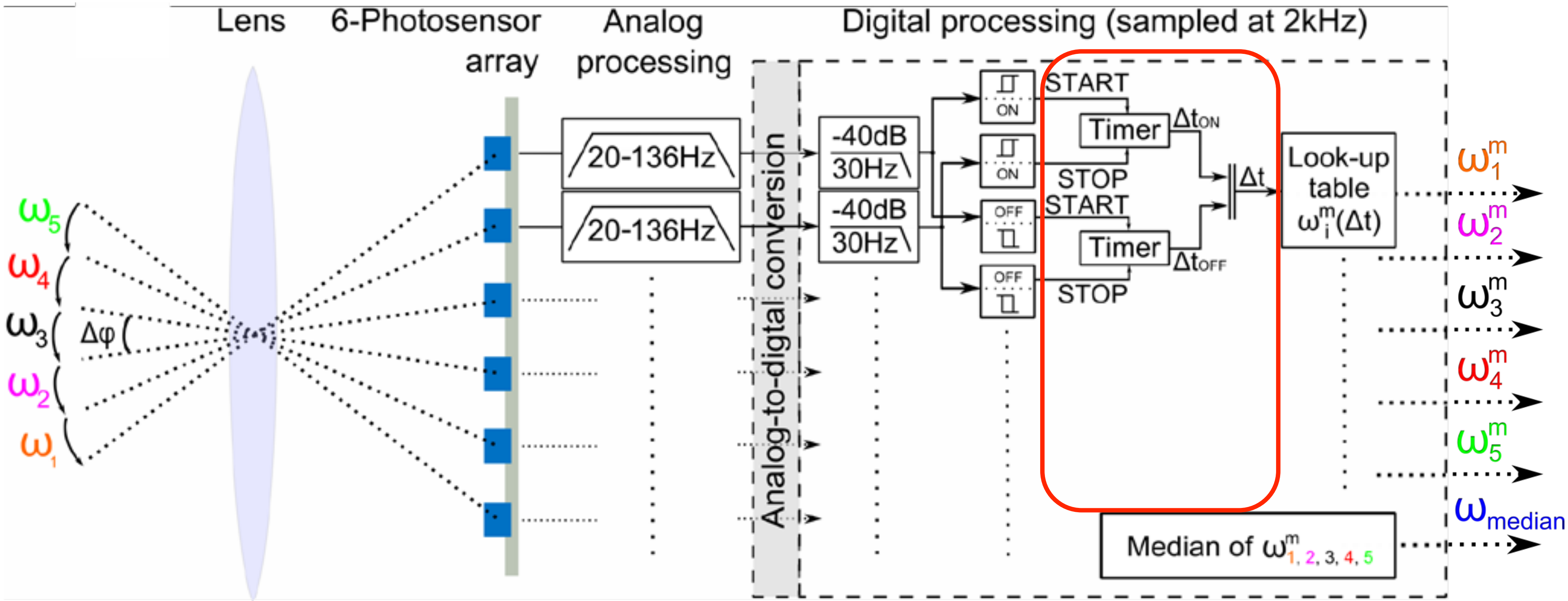


Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Optic flow processing

Time of travel scheme (*Blanes 86; Franceschini et al. 89, 92*):

6 processing steps

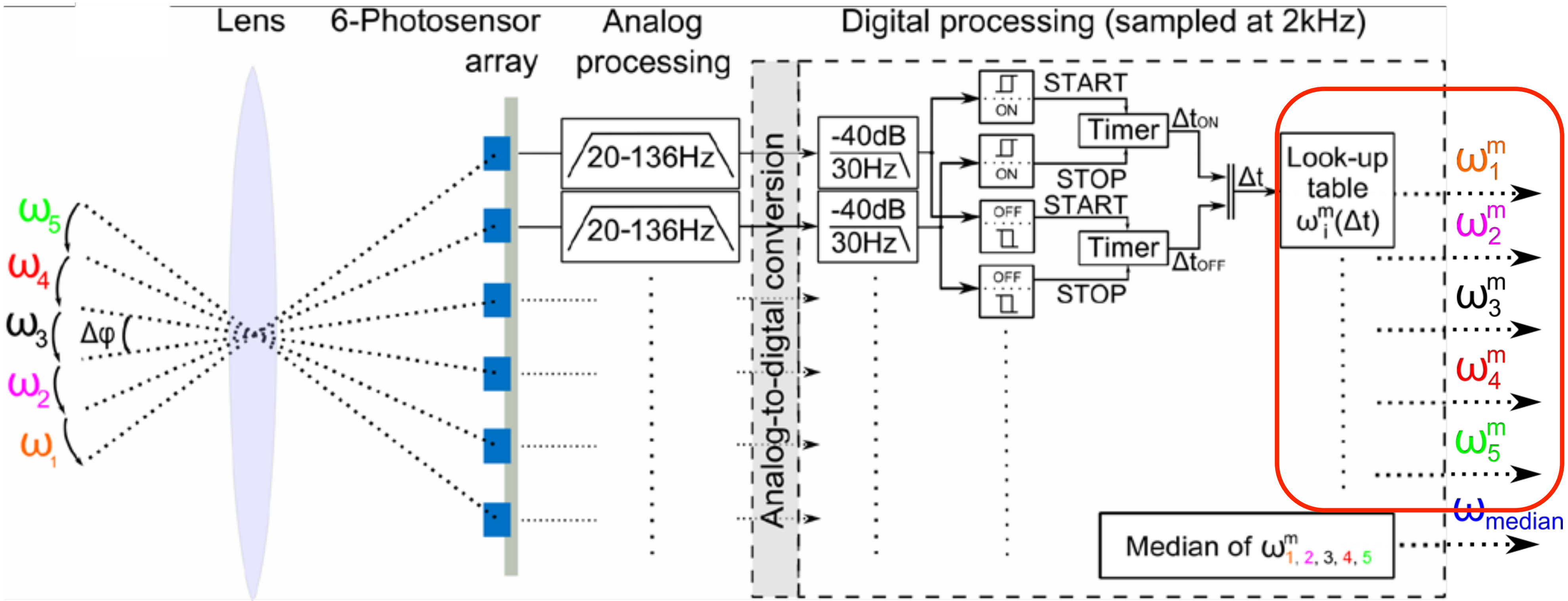


Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Optic flow processing

Time of travel scheme (*Blanes 86; Franceschini et al. 89, 92*):

6 processing steps

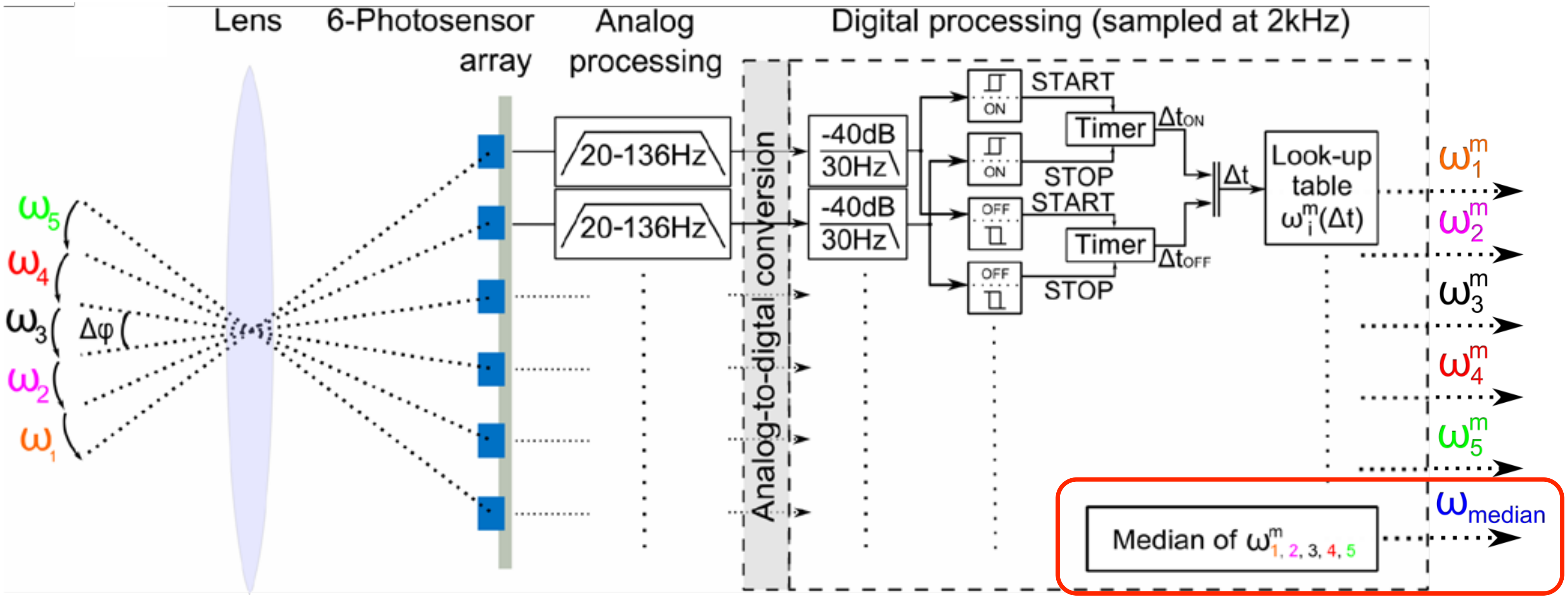


Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Optic flow processing

Time of travel scheme (*Blanes 86; Franceschini et al. 89, 92*):

6 processing steps

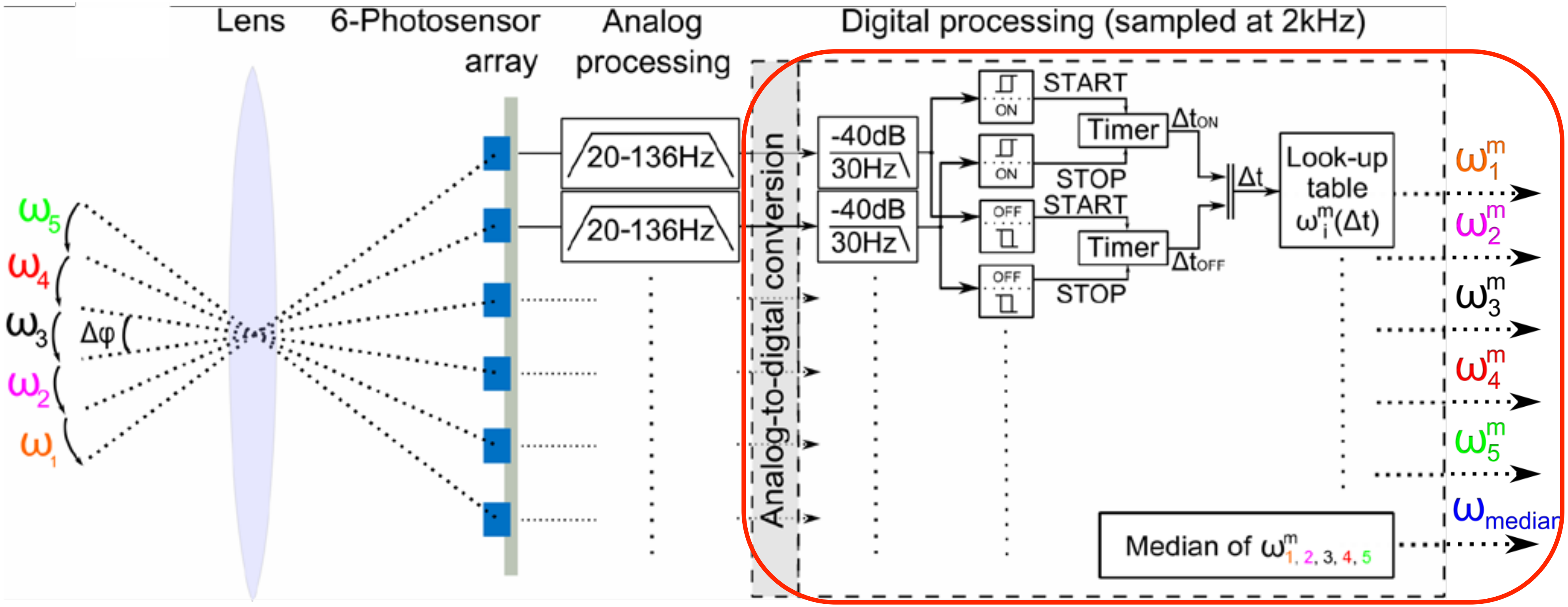


Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Optic flow processing

Time of travel scheme (*Blanes 86; Franceschini et al. 89, 92*):

6 processing steps

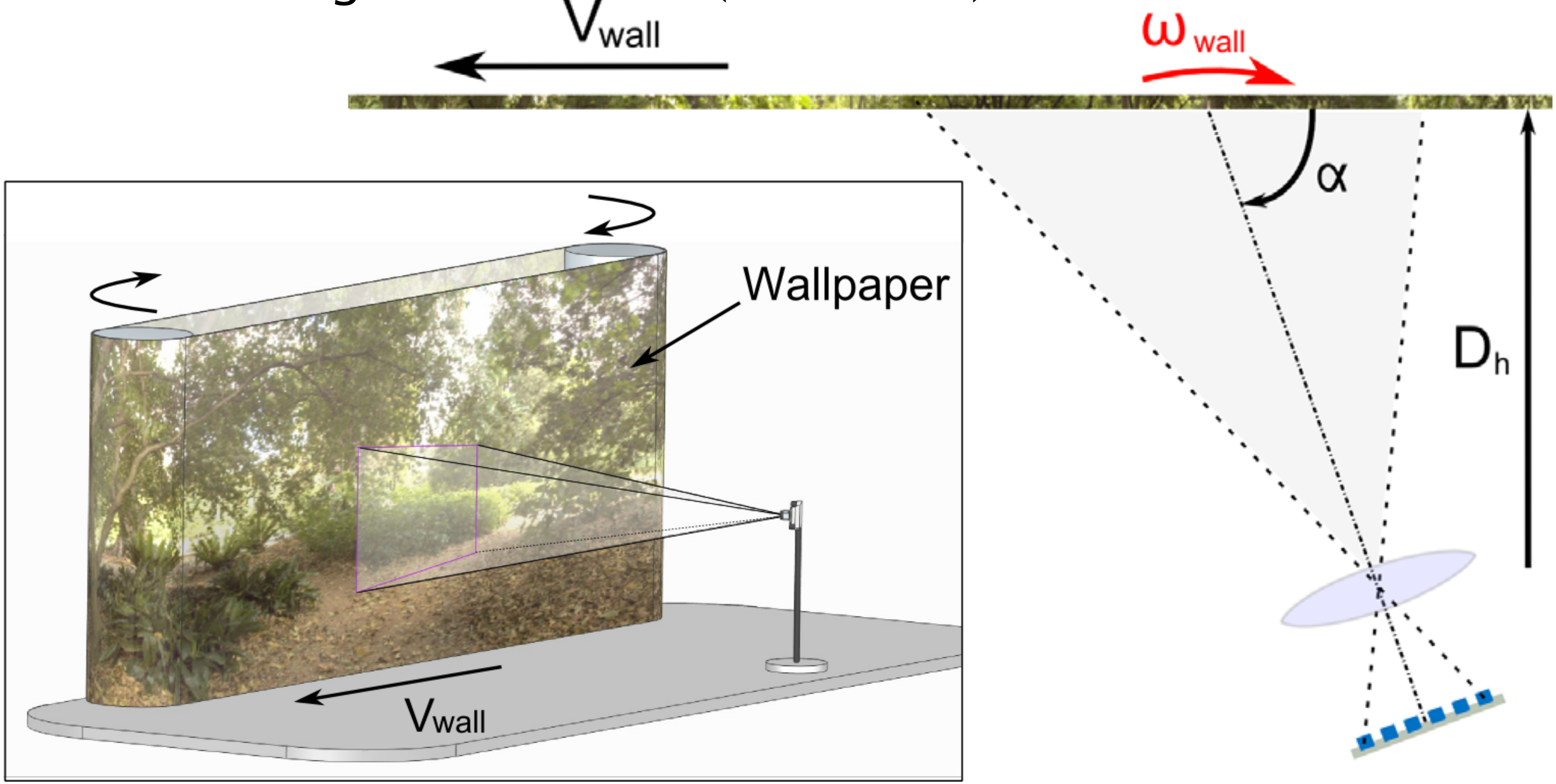


Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Implemented into a tiny 16bits dsPic microcontroller !!

Experiment

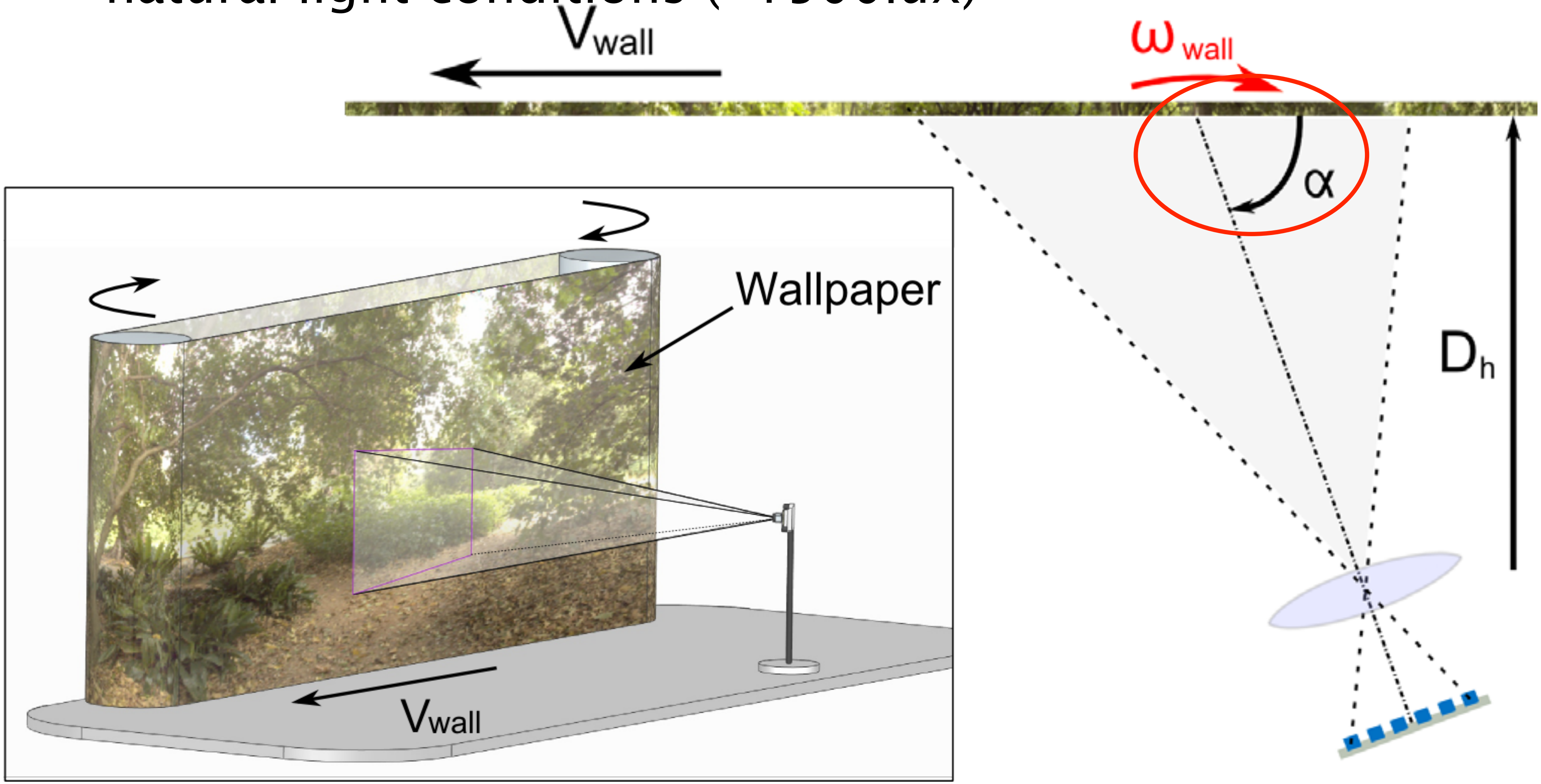
Indoor experiment on natural coloured scene under natural light conditions (~1500lux)



Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

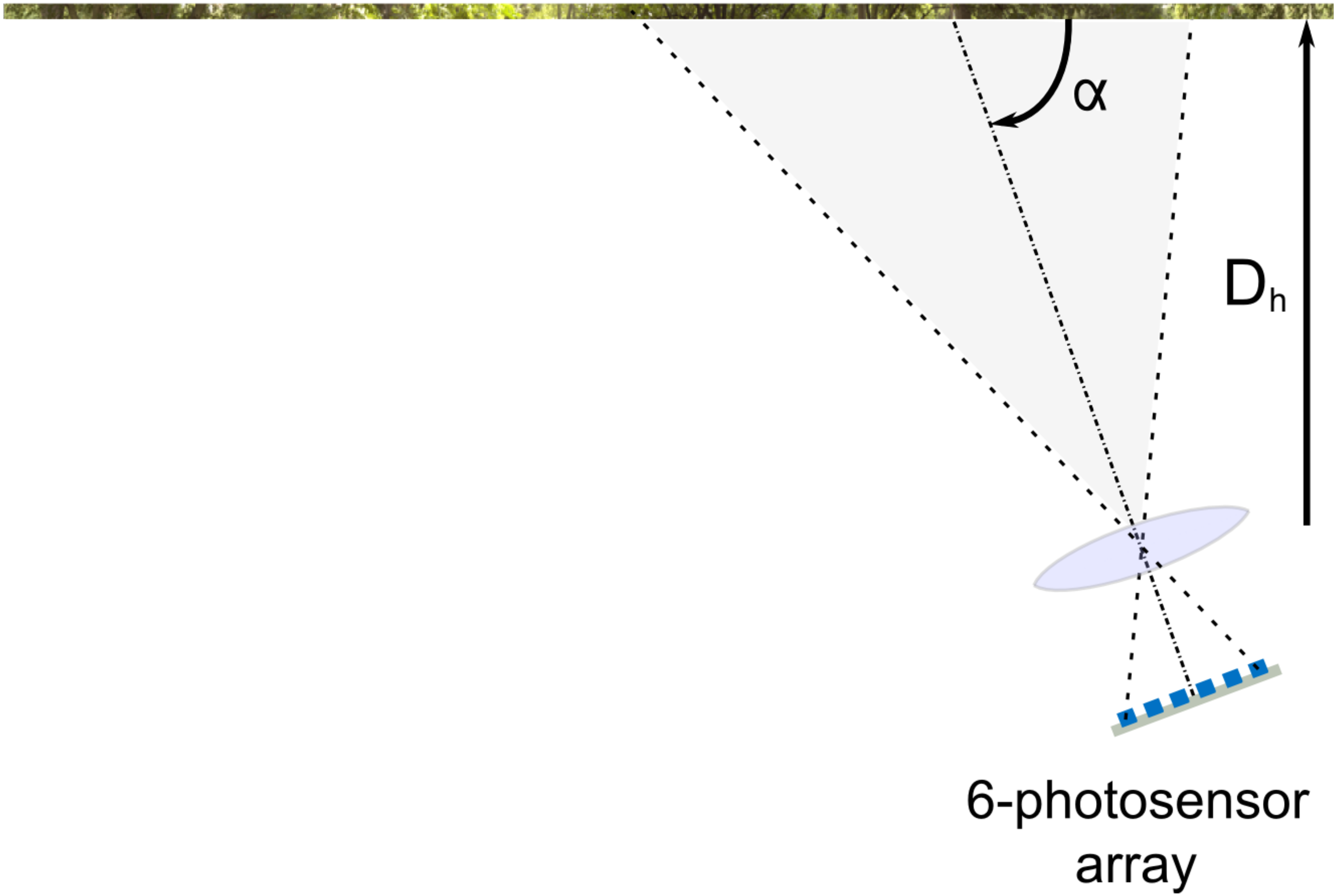
Experiment

Indoor experiment on natural coloured scene under natural light conditions (~1500lux)



Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

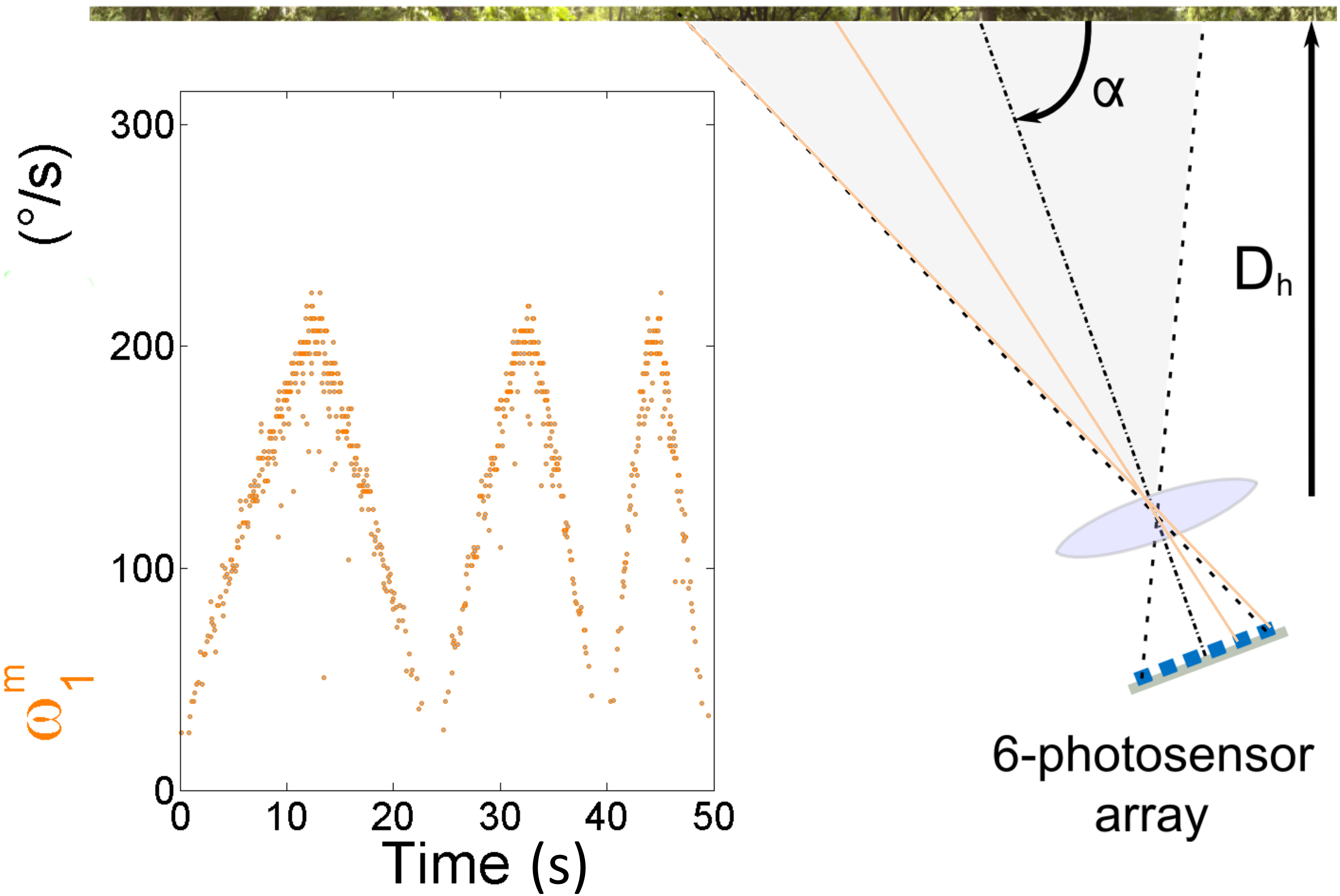
Results : α = 60°



Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

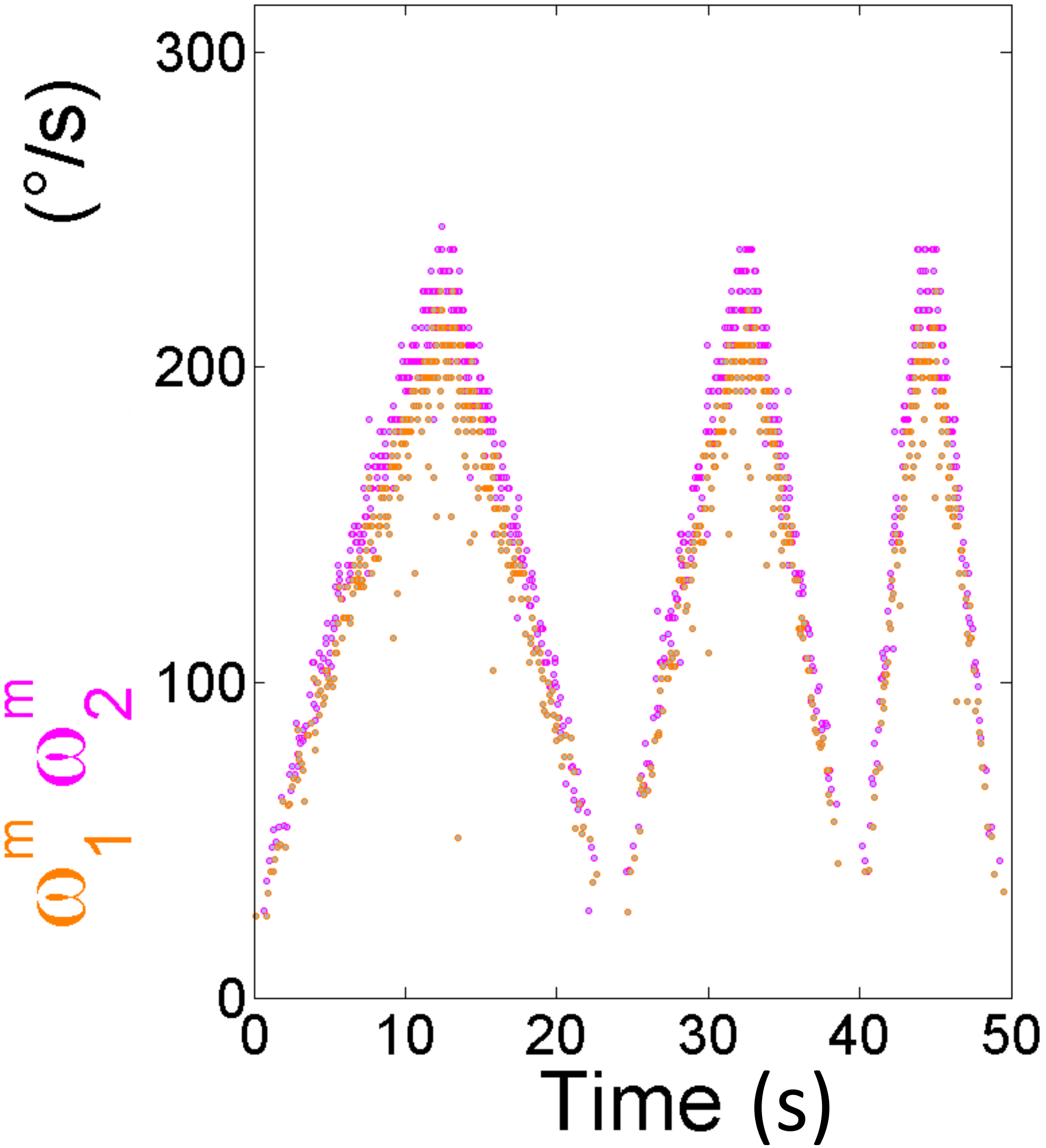
Results : α = 60°

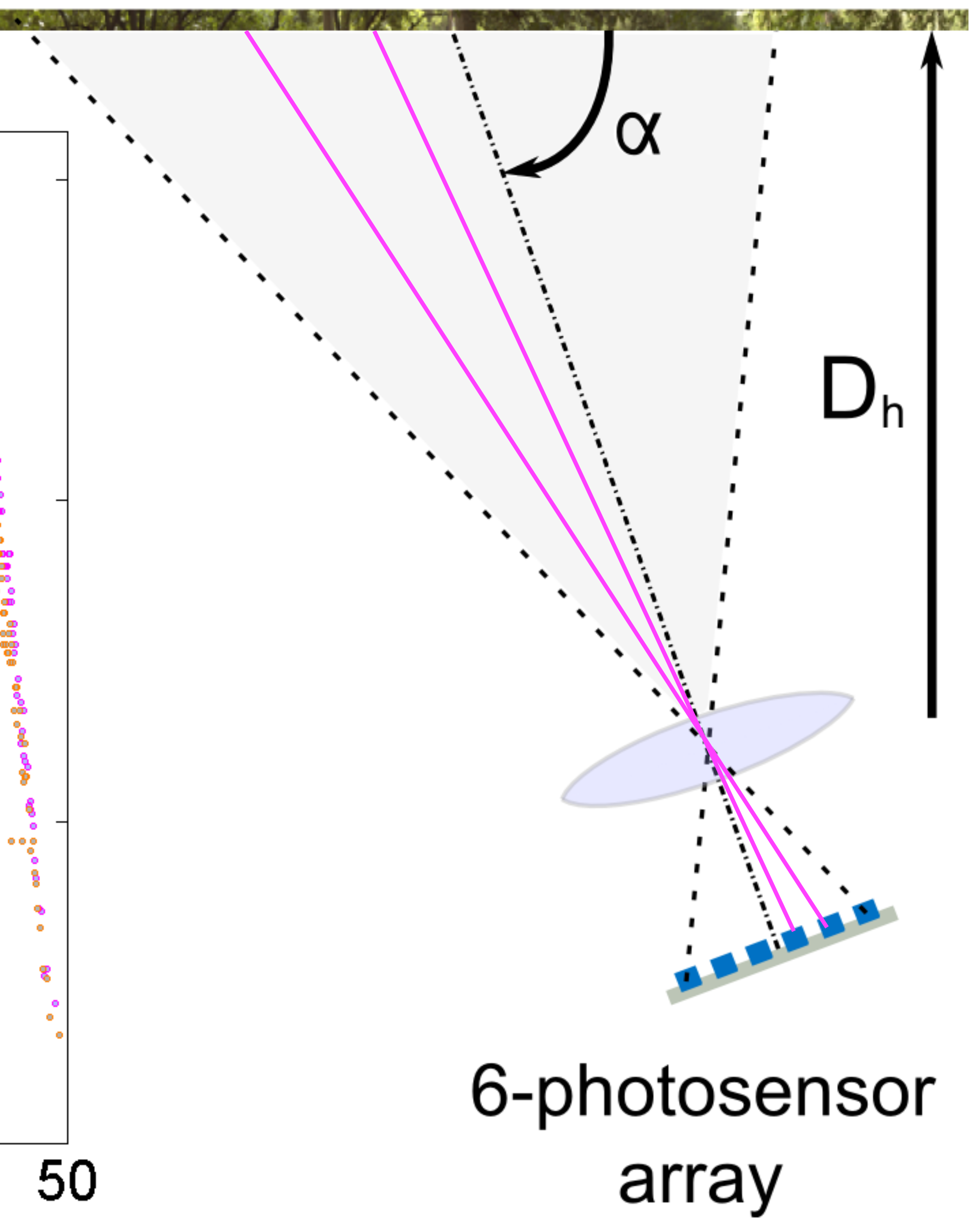
Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.



Results : α = 60°

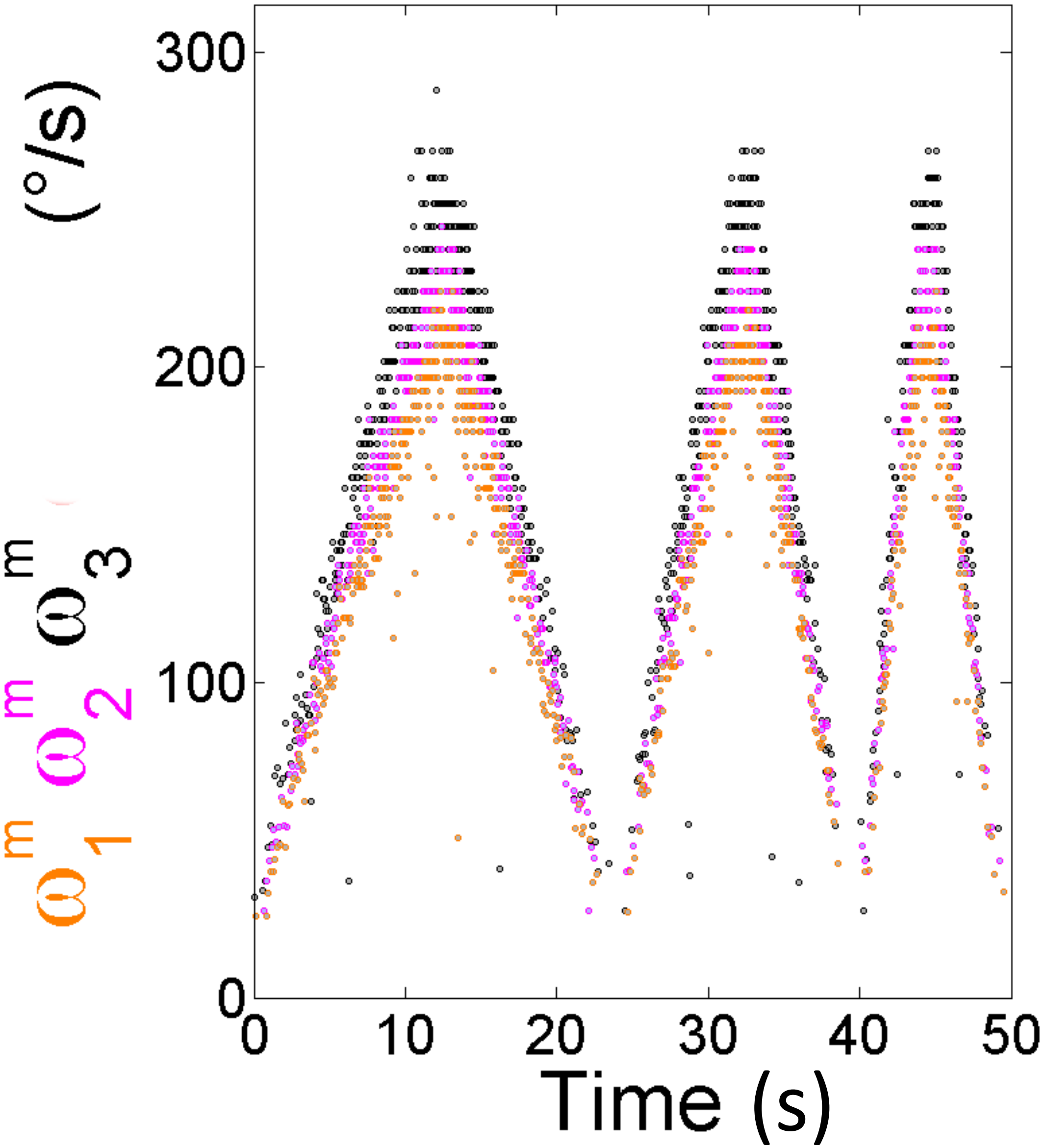
Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

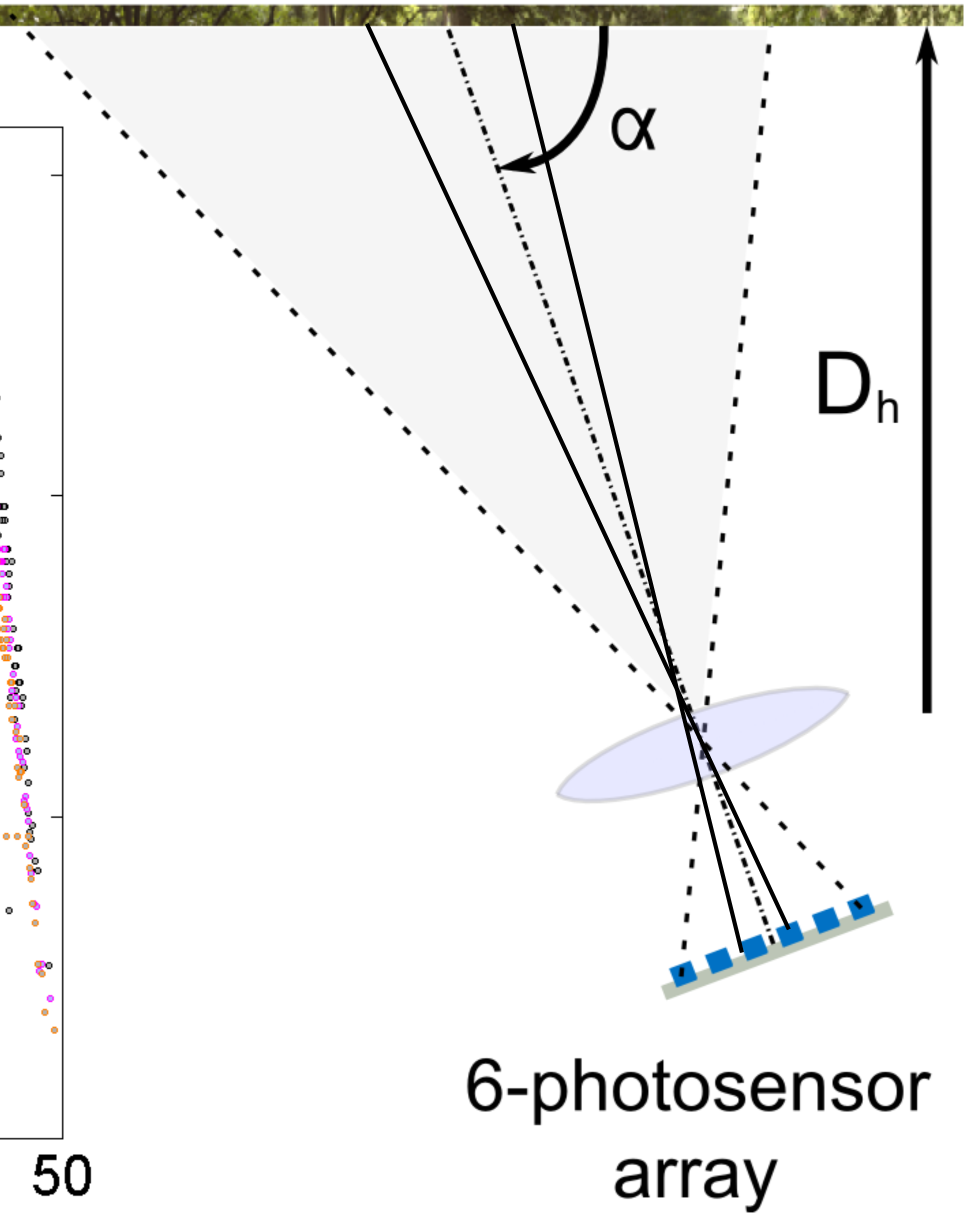




Results : $\alpha = 60°$

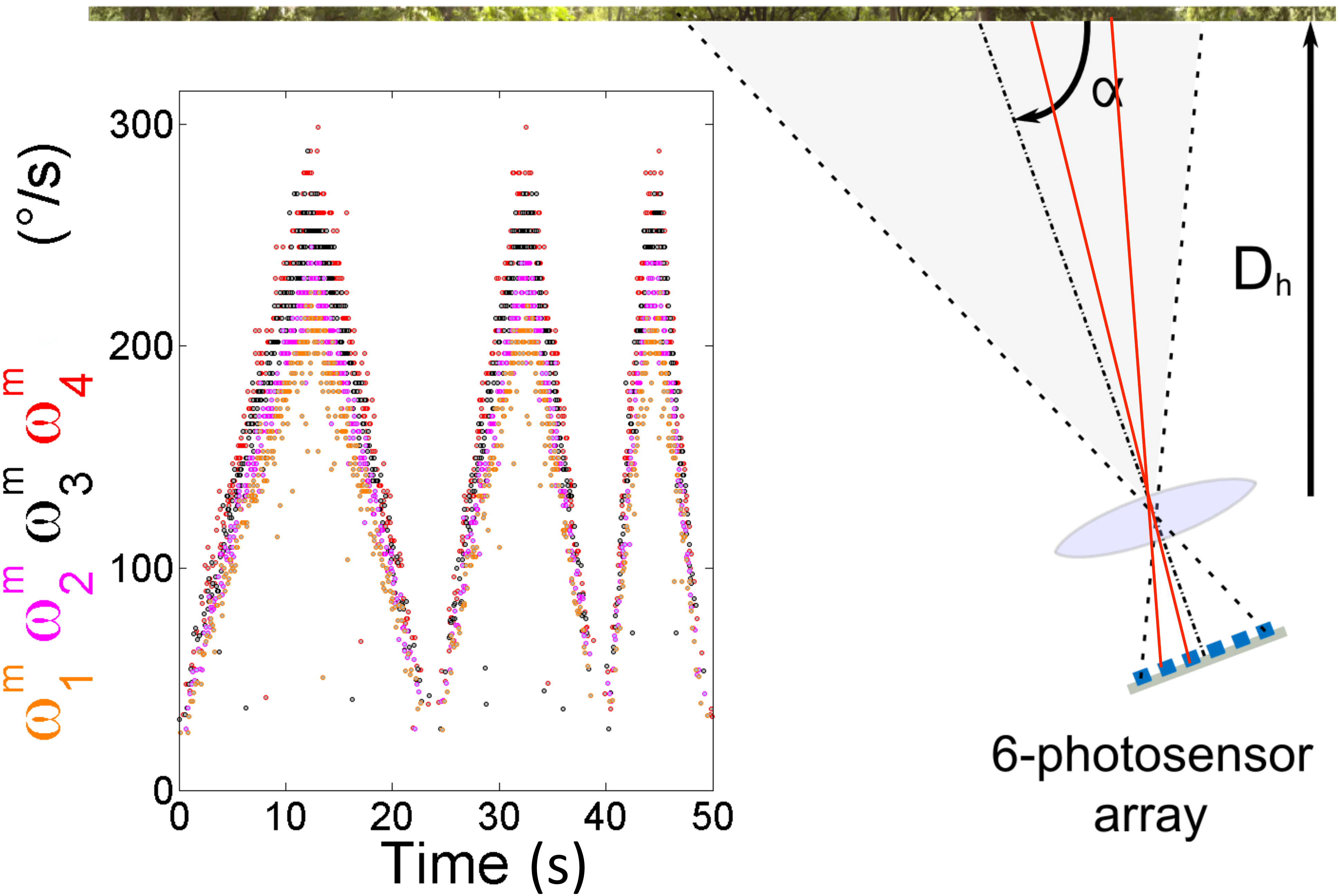
Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.





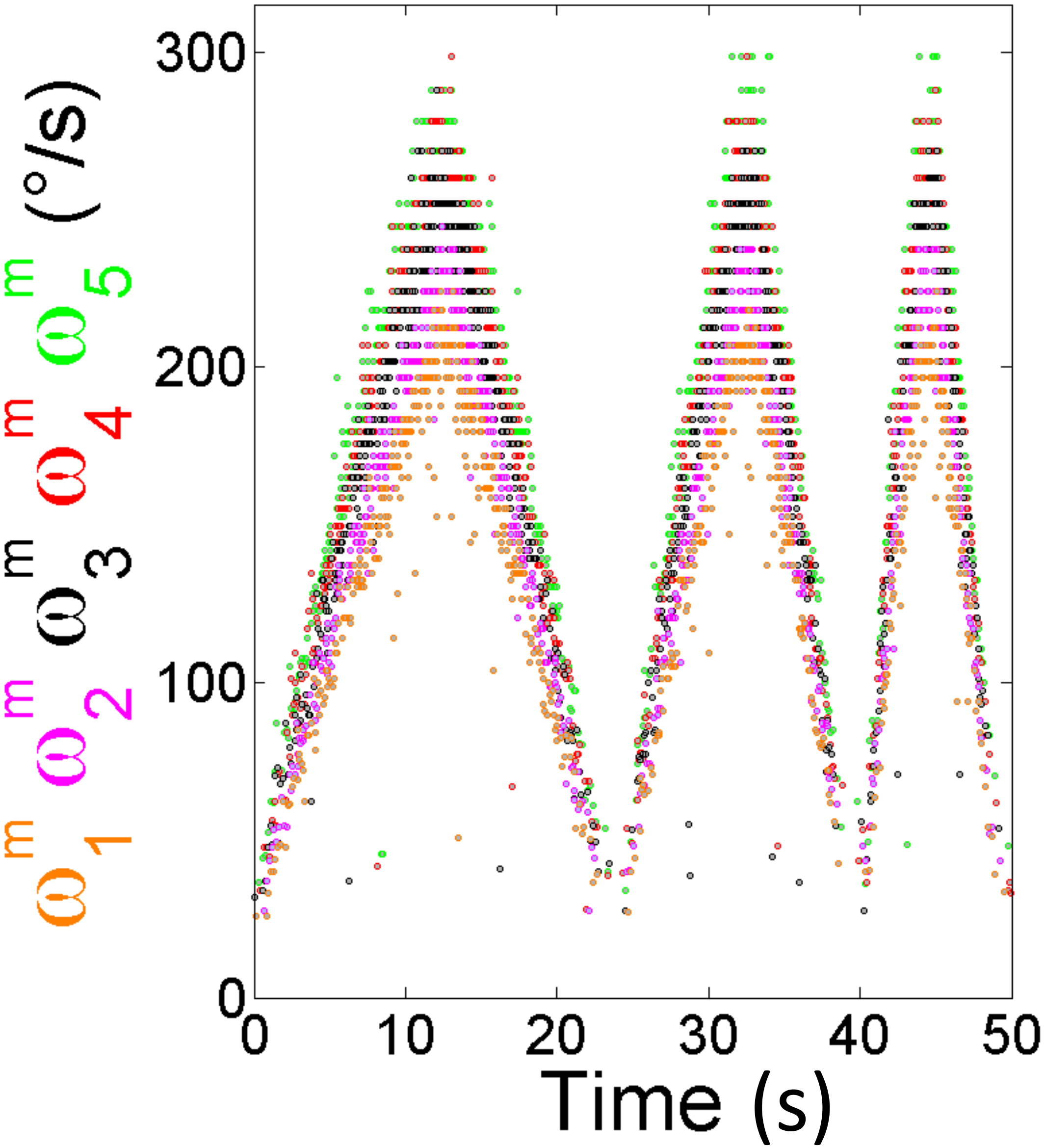
Results : α = 60°

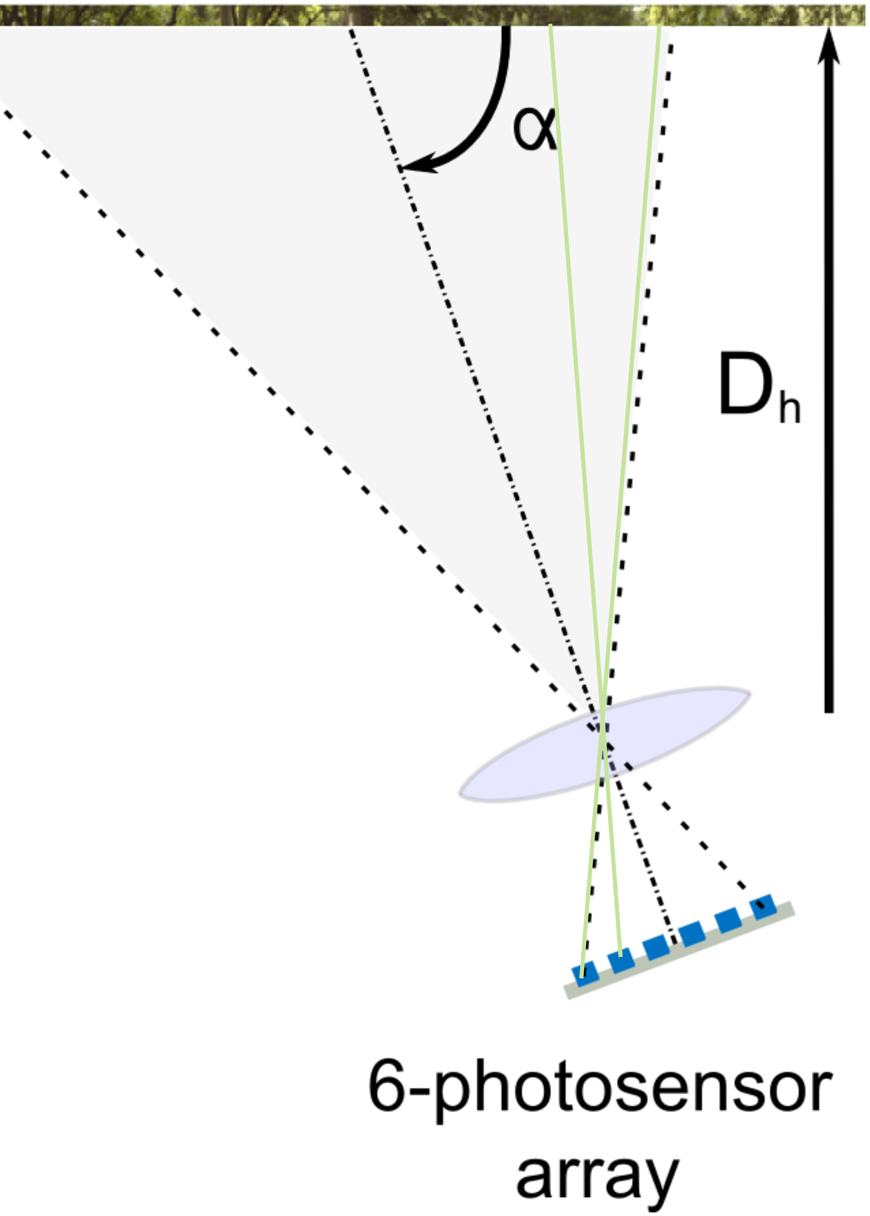
Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.



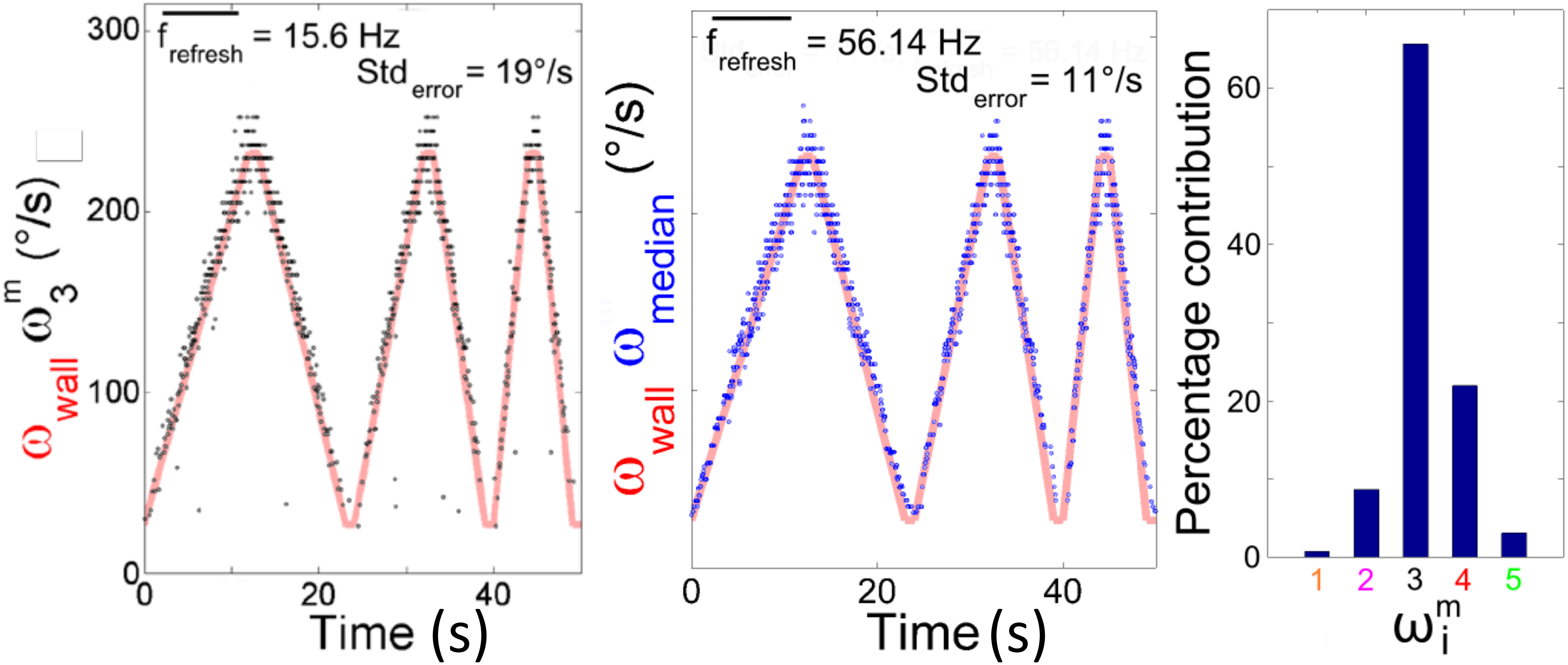
Results : α = 60°

Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.



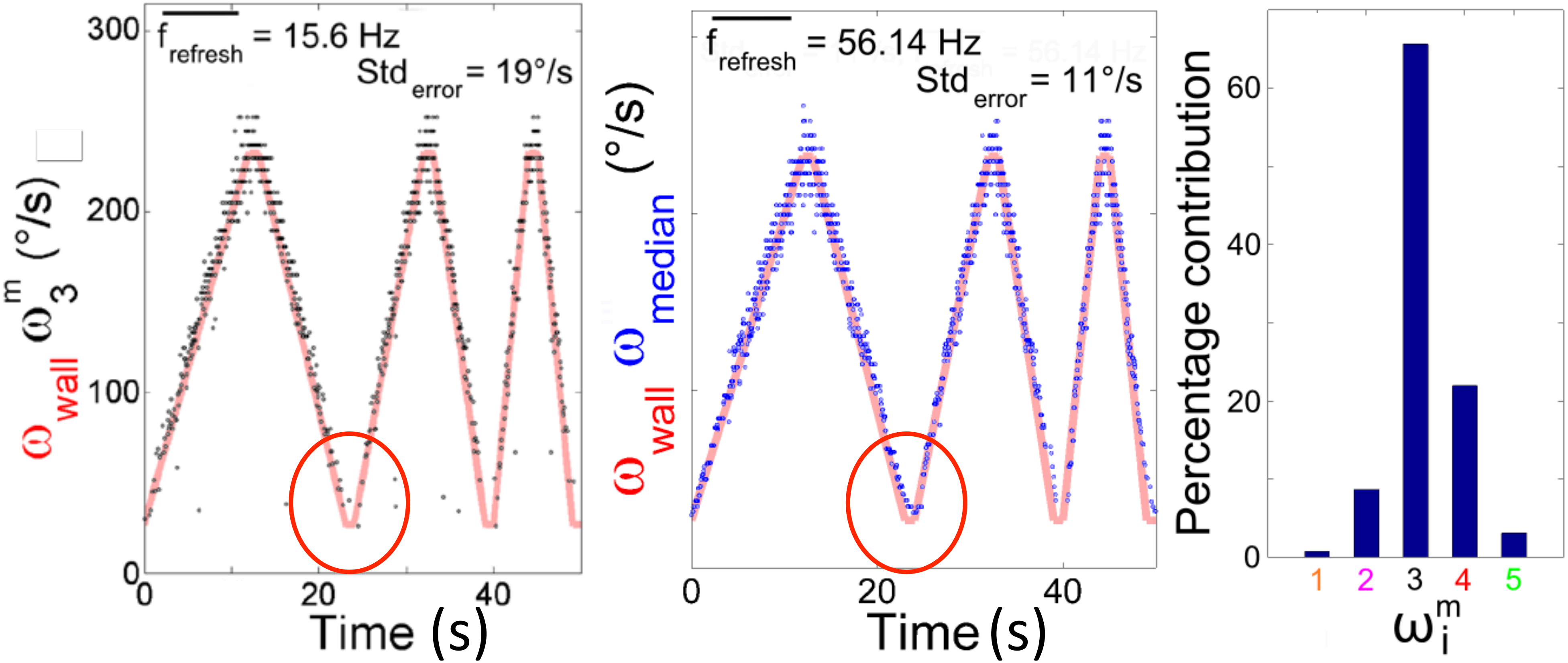


Results : $\alpha = 60°$



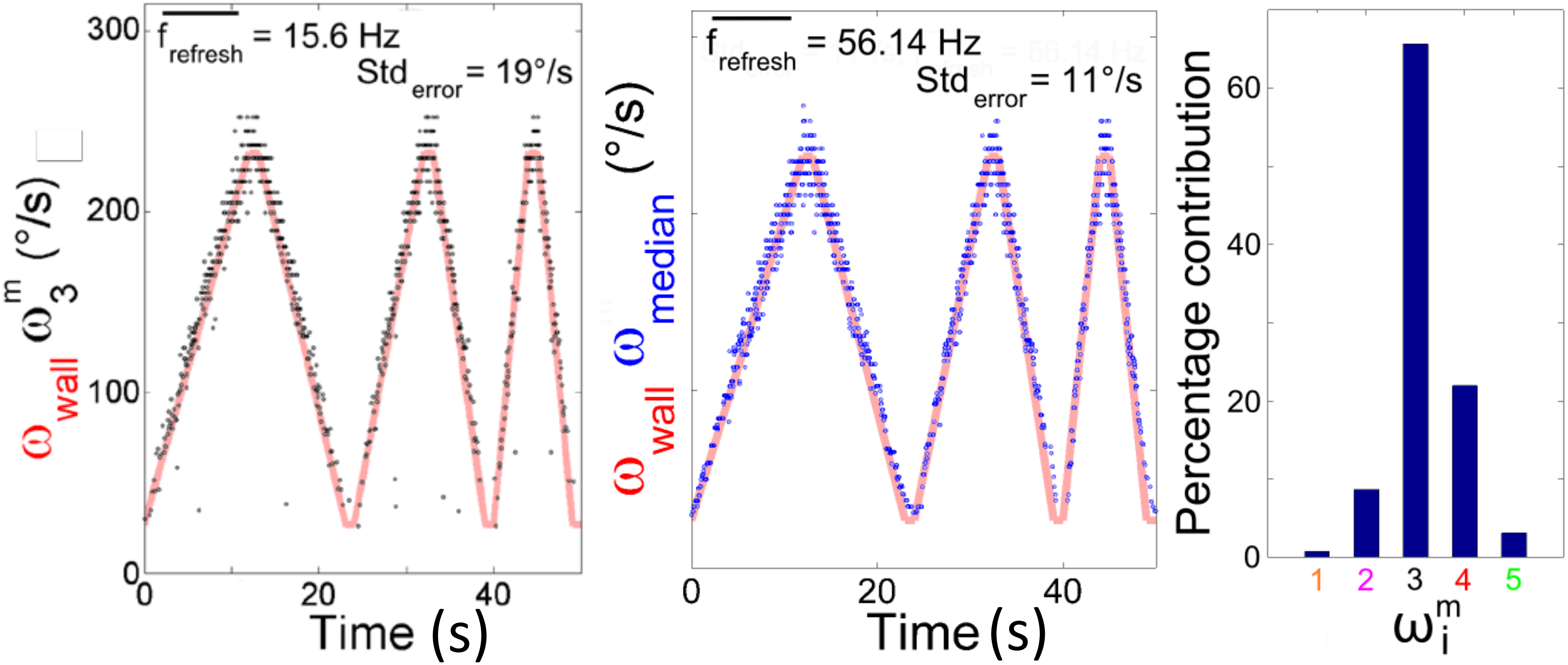
Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Results : α = 60°



Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

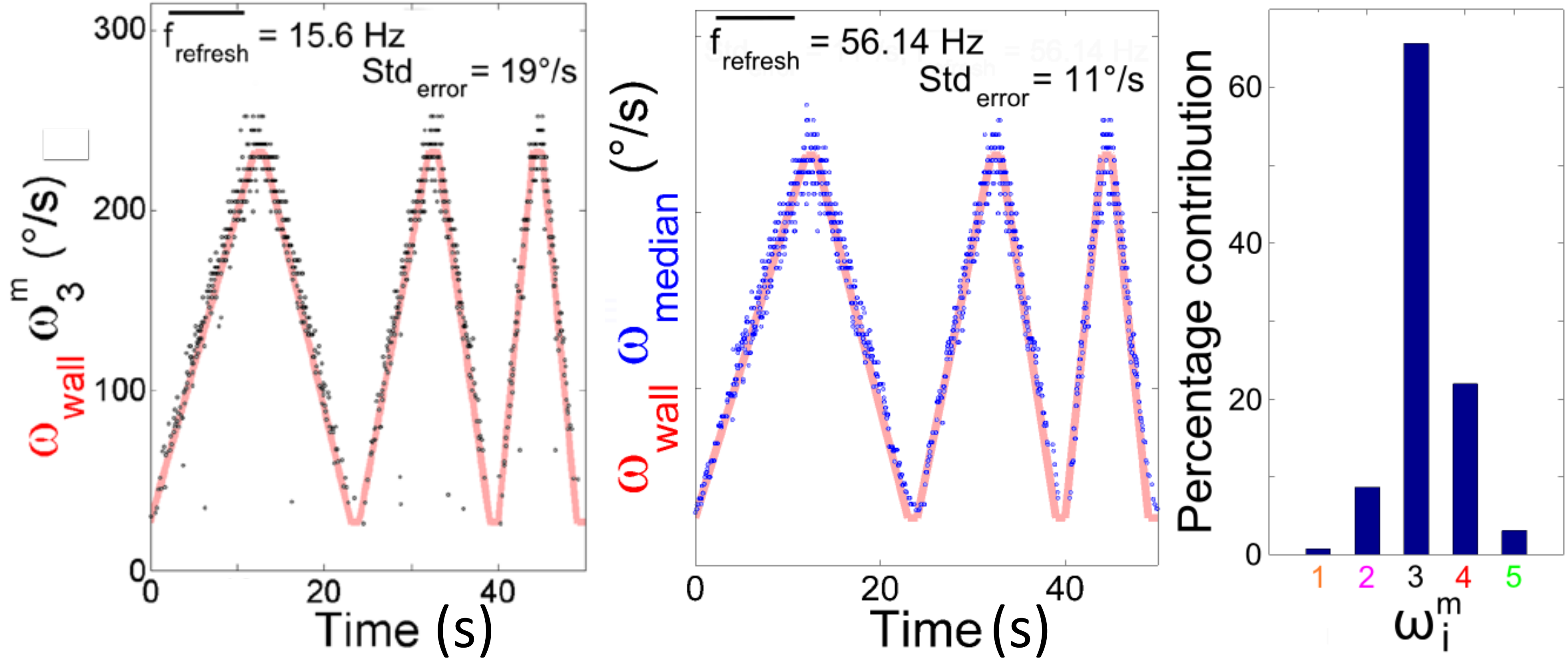
Results : α = 60°



Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

↘1.7-fold	**Single LMU output**	**Median value output**
Stderror	19 °/s	11 °/s
Frefresh		

Results : α = 60°



Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

↗ 4-fold	**Single LMU output**	**Median value output**
Stderror	19 °/s	11 °/s
Frefresh	13 Hz	56,14 Hz

Conclusion (*Part 2 & 3*)

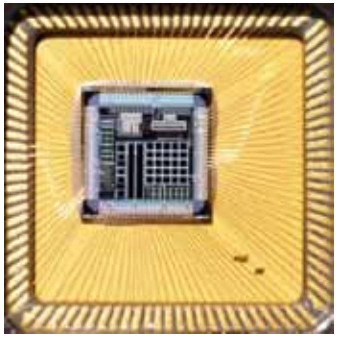
-> LSC-based sensor can provide 1 angular speed measurement in a narrow illuminance range (1.5 decades).

-> APIS-based sensor can provide 1 angular speed measurement in a 3-decade range (independant of the illuminance).

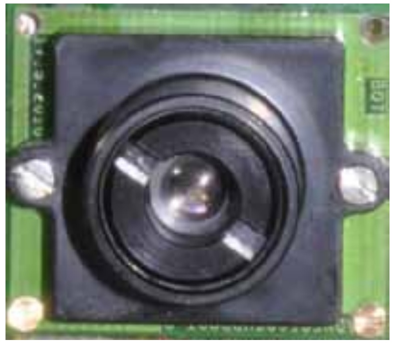
-> Mouse sensor can provide 2 angular speed (x-y) measurement with a better refreshed output 25Hz (high illuminance).

LSC

APIS



Mouse sensor

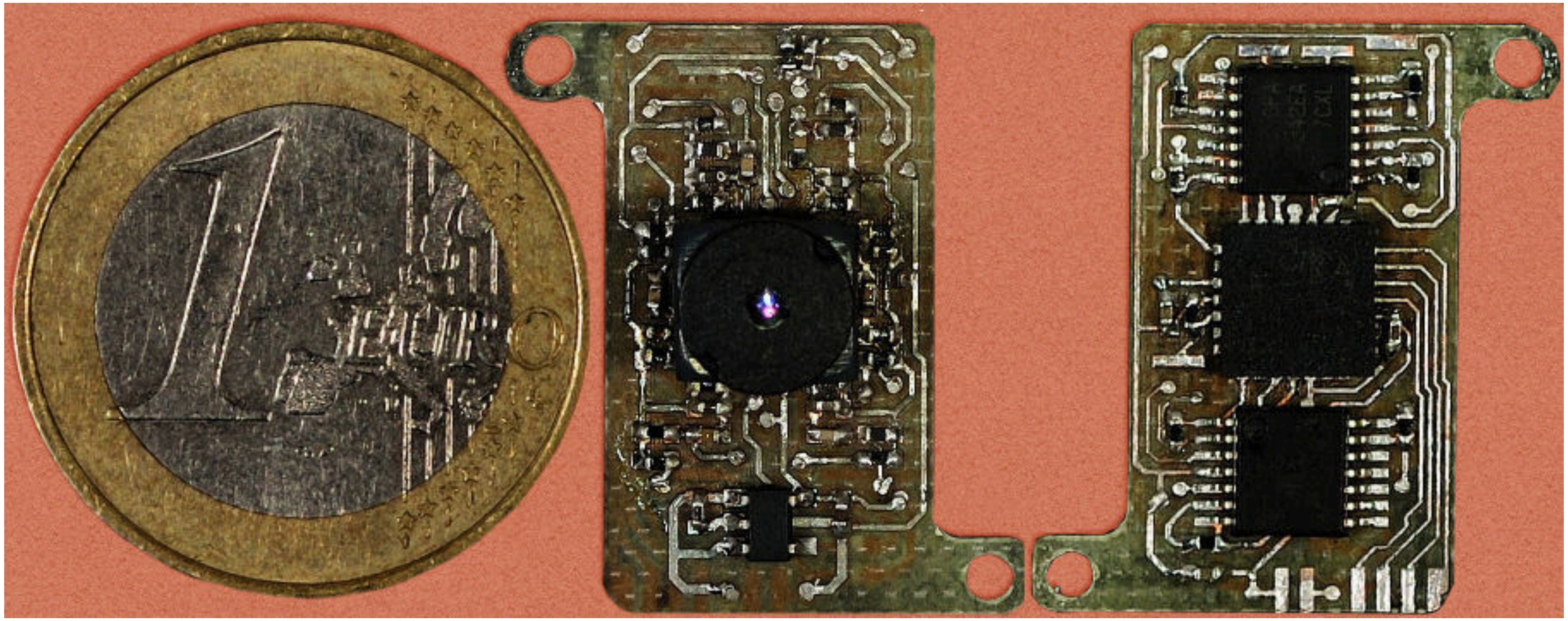


Conclusion (*Part 4*)

-> 1-gram insect-based visual motion sensor of 23.3 x 12.3 mm

-> 5 simultaneous 1-D angular speed measurements, $\omega \in [25°/s; 350°/s]$

-> 1 fused output : 1,7-fold more accurate (Std error=10˚/s) and 4-fold more refreshed output (up to $f_{refresh}$=65Hz on average) than a single LMU



Roubieu, Expert, Boyron, Fuschlock, Viollet and Ruffier (2011) IEEE-Sensors Conf.

Any further informations ?

Please contact :

Stéphane Viollet
stephane.viollet@univmed.fr

Franck Ruffier
franck.ruffier@univmed.fr