A bio-inspired celestial compass for a hexapod walking robot in outdoor environment

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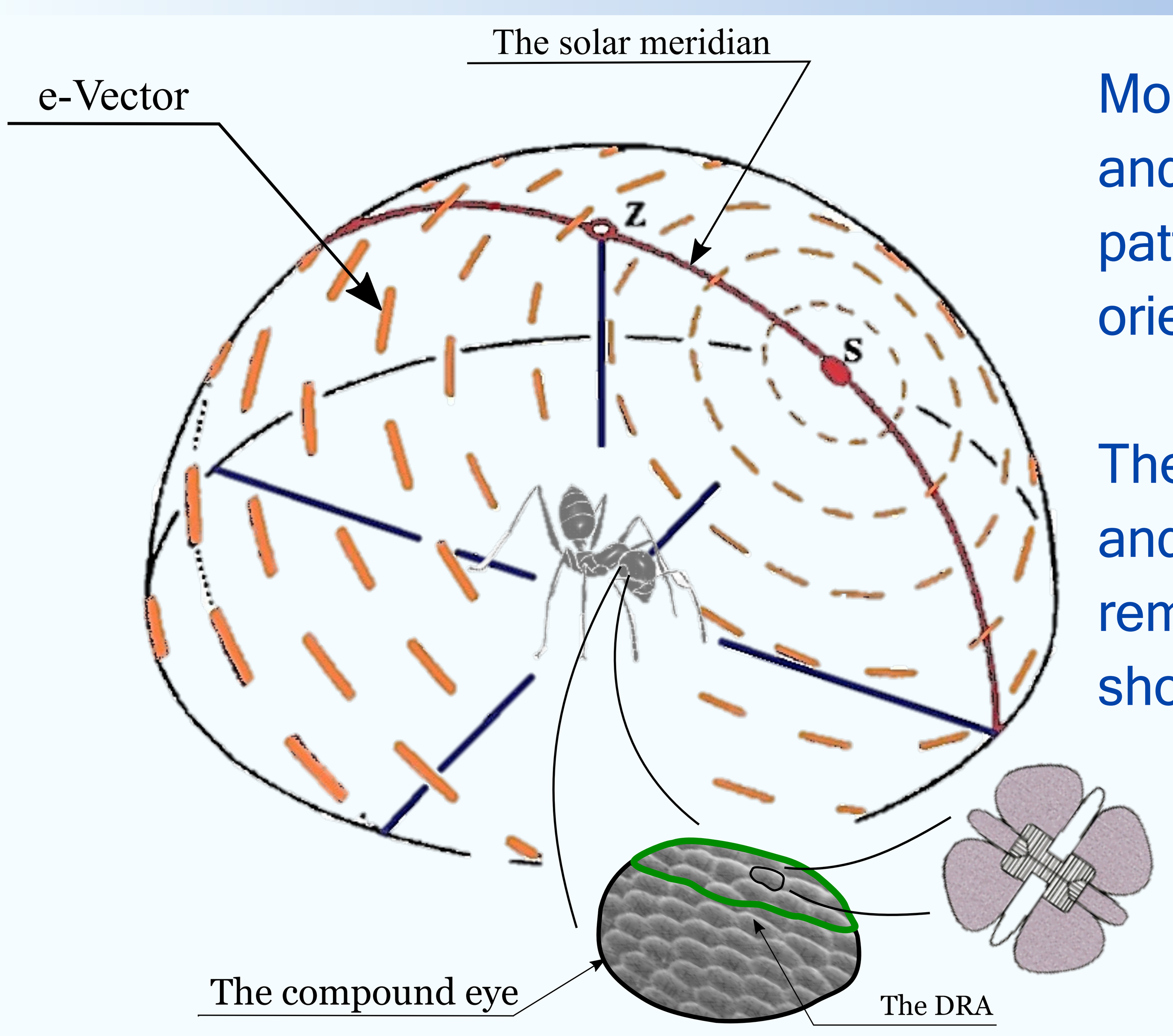
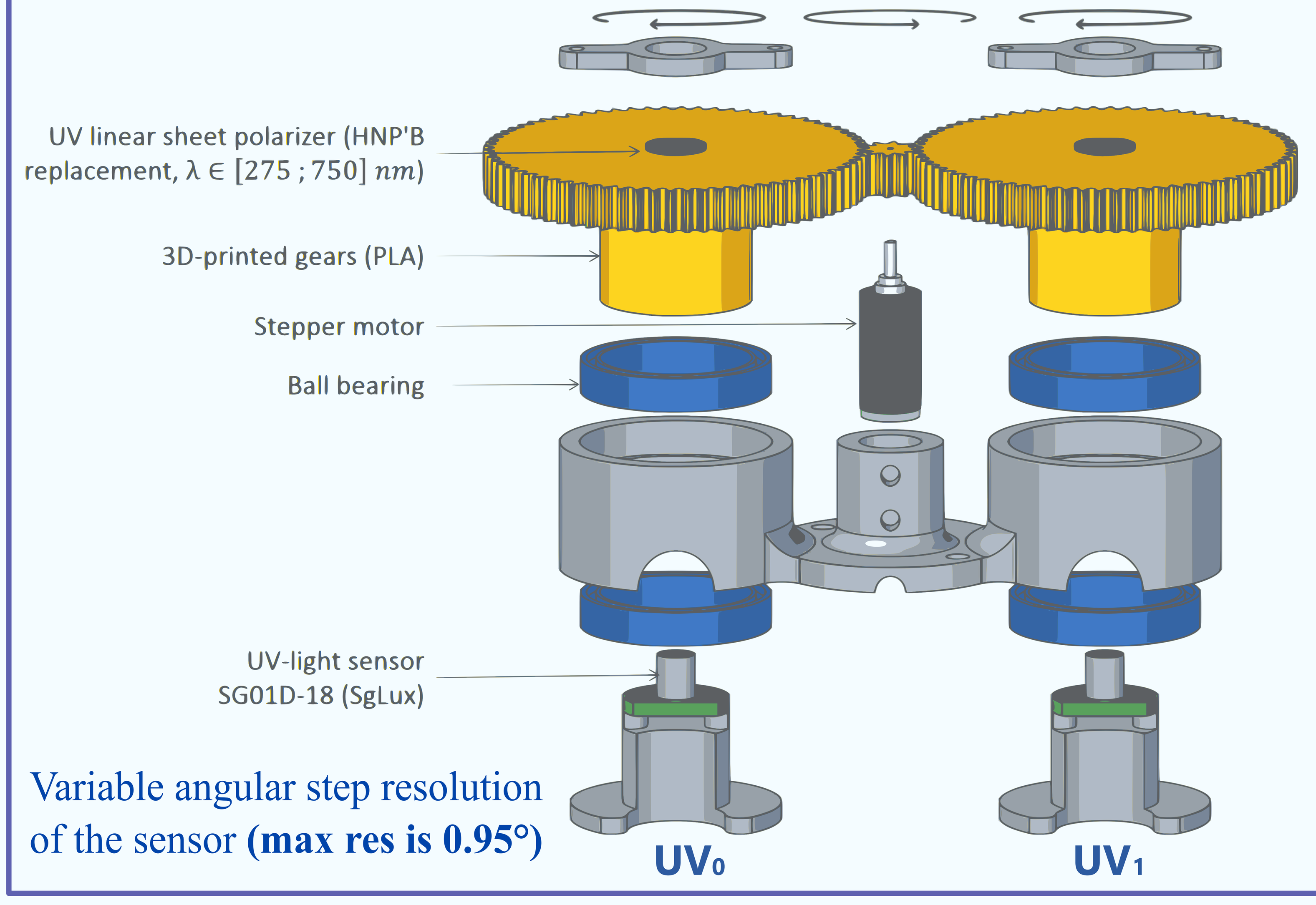
The polarized light detection in insects



Most insects like desert ants and bees use the polarization pattern of skylight to get their orientation [1].

The skylight is linearly polarized and the direction of polarization remains slightly constant within short times.

The celestial compass



Variable angular step resolution of the sensor (**max res is 0.95°**)

The signal processing unit

Let UV_0 and UV_1 be the POL-sensor raw responses depending on x, the gear rotation angle in $[0,2\pi]$:

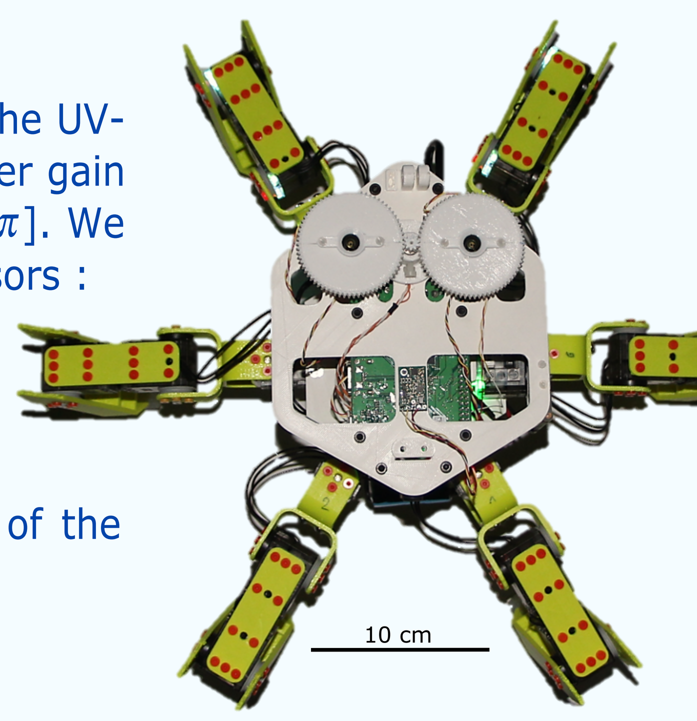
$$\begin{cases} UV_0(x) = A_0 + B_0 \cdot cos(2(x+\psi)) \\ UV_1(x) = A_1 + B_1 \cdot cos(2(x+\psi+\frac{\pi}{2})) \end{cases}$$

where A_0 and A_1 depend on the ambient UV-light and the inner offset of the UV-light sensors, B_0 and B_1 depend on the degree of polarization and the inner gain of the UV-light sensors, and ψ is the solar meridian direction angle in $[0,\pi]$. We then define p(x) as the log ratio of both normalized UV_0 and UV_1 POL-sensors :

$$p(x) = log_{10}\left(\frac{UV_1^{nc}(x)}{UV_0^{nc}(x)}\right)$$

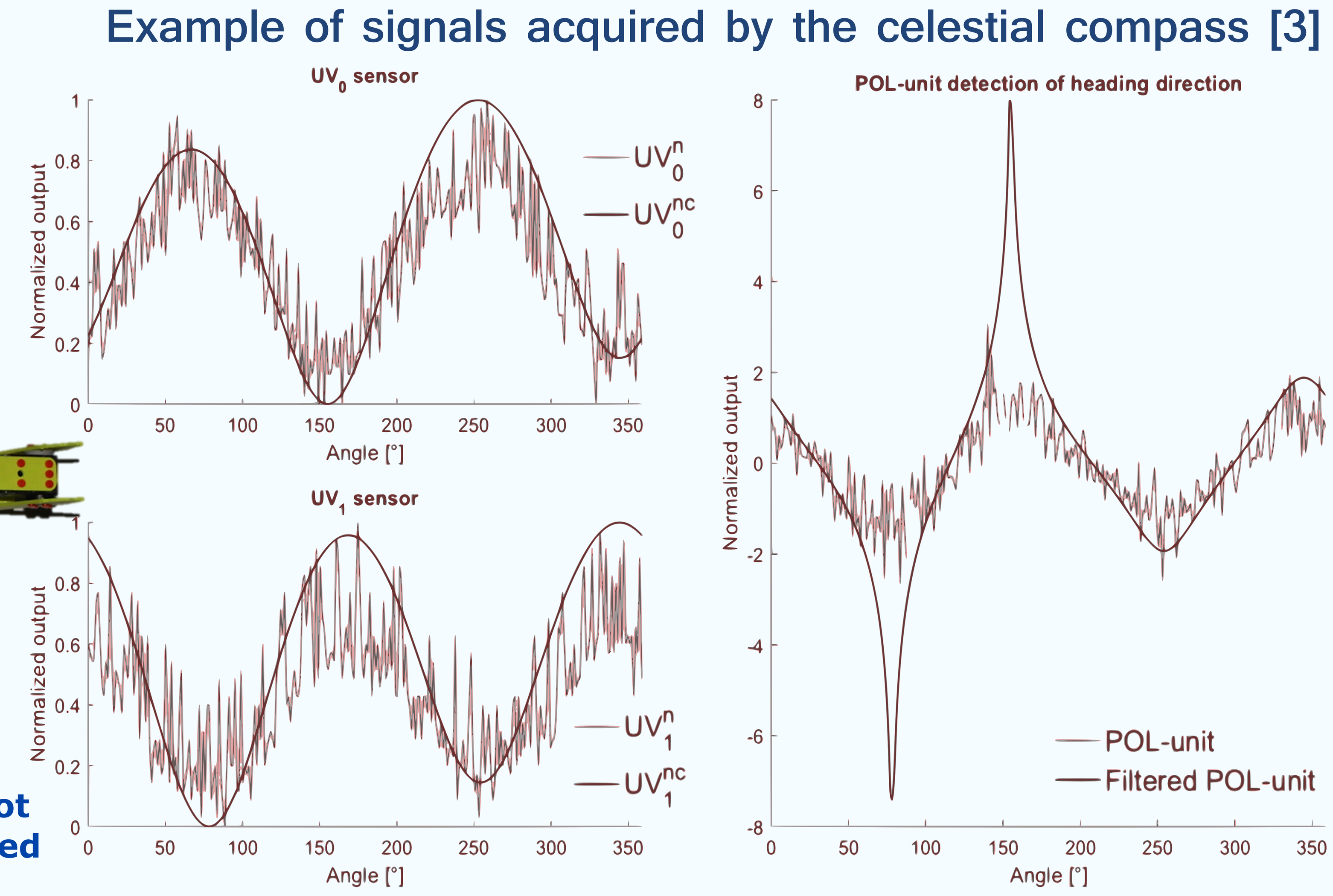
where nc stands for normalized and corrected (only the first harmonic of the raw signal is considered). Finally, ψ is computed using the p(x) minima:

$$\psi = \frac{1}{2}\left(\underset{x\in[0;\pi]}{\arg\min}\, p(x) + \underset{x\in[\pi;2\pi]}{\arg\min}\, p(x) - \pi\right)$$



Top view of the Hexabot robot equipped with the UV-polarized light compass [2].

Example of signals acquired by the celestial compass [3]



Results

Performances of the celestial compass under various weather conditions [4]

PEAK-TO-PEAK MAGNITUDE OF RAW SIGNALS

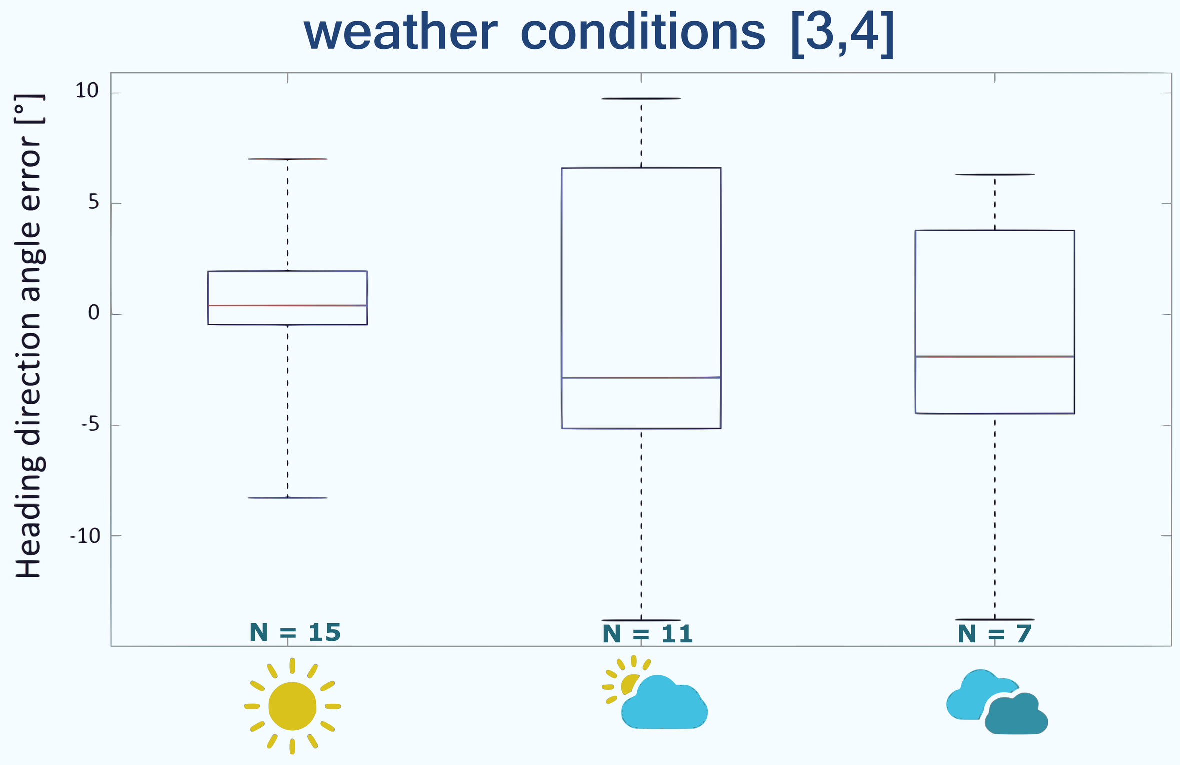
Conditions	$UV_{0,P-P}$	Cv_0	$UV_{1,P-P}$	Cv_1	n
(a)	333.19	6%	396.00	6%	21
(b)	79.47	22%	124.93	22%	15
(c)	959.06	5%	1137.11	5%	36
(d)	176.11	18%	111.22	21%	36

STEADY STATE ERROR BETWEEN NORMALIZED AND FILTERED DATA

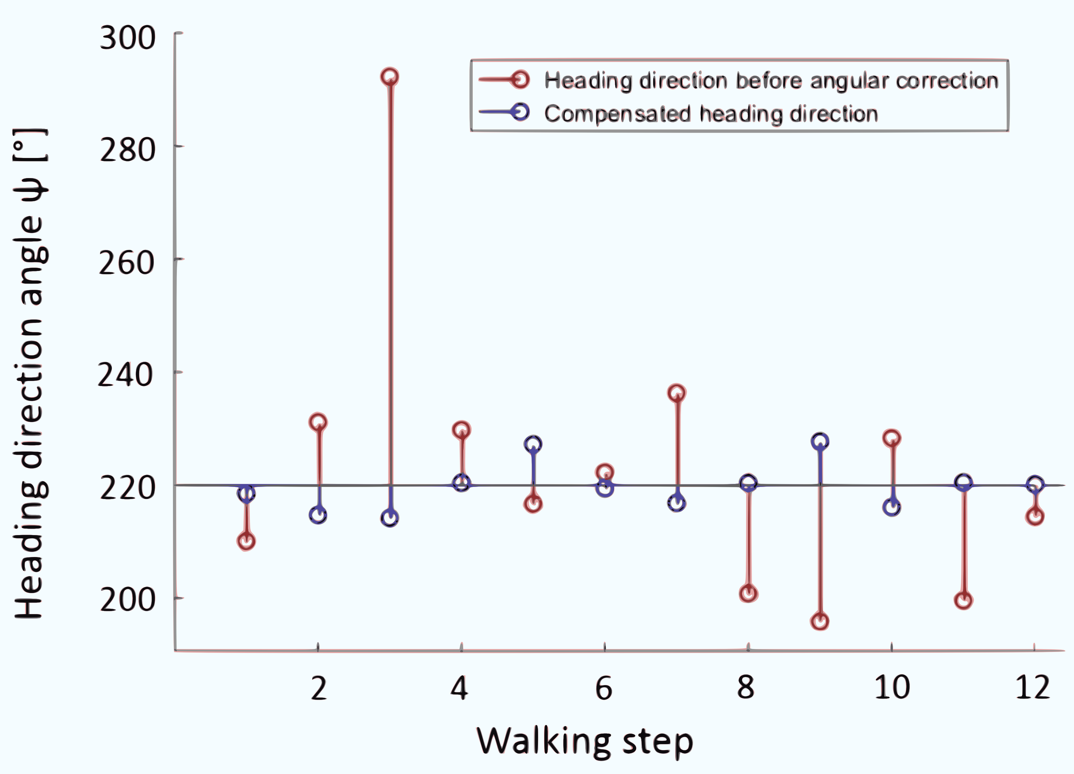
Conditions	$\overline{\varepsilon_0}$	$Cv[\varepsilon_0]$	$\overline{\varepsilon_1}$	$Cv[\varepsilon_1]$	n
(a)	4.28e-03	6%	4.83e-03	4%	21
(b)	9.02e-03	36%	7.31e-03	32%	15
(c)	3.99e-03	10%	4.14e-03	5%	36
(d)	6.14e-03	27%	8.36e-03	19%	36

Cv: coefficient of variation; $\overline{\varepsilon}$: average mean squared error; n: number of tests. Conditions : (a) February 2017 clear sky (UV Index = 1), (b) February 2017 covered sky, (c) April 2017 clear sky (UV index = 7), (d) April 2017 covered sky.

Performances of reorientation after yaw displacements under various weather conditions [3,4]



Heading lock over a straight-forward walking task [3,4]



Conclusion

Heading direction error from **0.3° under clear sky** to 1.9° under worse weather conditions [3,4].

High reliability [3,4].

Even under poor weather conditions, these results suggest **interesting precision** to make the optical compass **suitable for field robotics** [3,4].

References

[1] T. Labhart. Polarization-opponent interneurons in the insect visual system. Nature, vol. 331, no 6155, pp. 435-437, 1988.

[2] J. Dupeyroux, G. Passault, F. Ruffier, S. Viollet, J. Serres. Hexabot: a small 3D printed six-legged walking robot designed for ant-like navigation tasks. 20th IFAC World Congress, Toulouse, France, accepted 2017.

[3] J. Dupeyroux, J. Diperi, M. Boyron, S. Viollet, J. Serres. A novel insect-inspired optical compass sensor for an hexapod walking robot. Intelligent Systems and Robots (IROS), 2017 IEEE/RSJ International Conference on. IEEE, submitted 2017.

[4] J. Dupeyroux, J. Diperi, M. Boyron, S. Viollet, J. Serres. A bio-inspired celestial compass applied to an ant-inspired robot for autonomous navigation. Mobile Robots (ECMR), 2017 European Conference on. IEEE, submitted 2017.