

Bio-inspired Use of skylight polarization to measure heading for automotive industry

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Localization systems mostly make use of Global Navigation Satellite System (GNSS) and Inertial Measurement Units (IMUs). Nowadays, there are off-the-shelf complete navigation systems incorporating GNSS, IMU and magnetic compass for a footprint of only 2x2cm² and a mass of 5 grams. However, there are areas where the GNSS signal is obscured (urban canyons, metallic structures, interferences with other systems, poor weather conditions) or even areas where the Earth's magnetic field is too disturbed to provide a reliable measurement.

For autonomous vehicles, a reliable navigation system is necessary. To overcome the limitations of the current systems, we are currently developing an optical compass (Fig. 1) based on a bio-inspired approach derived from behavioral studies on desert ants *Cataglyphis*. This small animal has indeed a dedicated area, called the dorsal rim area, in the dorsal part of the compound eye sensitive to the polarized light of the sky. Thanks to this sensitivity to polarization light, ants estimate their orientation with respect to the pattern of polarization of the sky and are able to combine it with other information for localization purposes with respect to their nest.

Similarly, our objective is to develop a first prototype of an automotive-specific sensor (Fig. 1), and determine its limits outdoors in real conditions. Especially, we will study the effect of atmospheric conditions on both the accuracy and the stability of the measured optical heading measurement. We will use a division-of-focal-plane polarization-imaging sensor with a fisheye lens to mimic an ant's eye (Fig. 1), in order to take snapshots of the skylight polarization pattern, then to deduce optically the vehicle's heading and to compare it to GNSS or magnetic field-based compasses measurements.

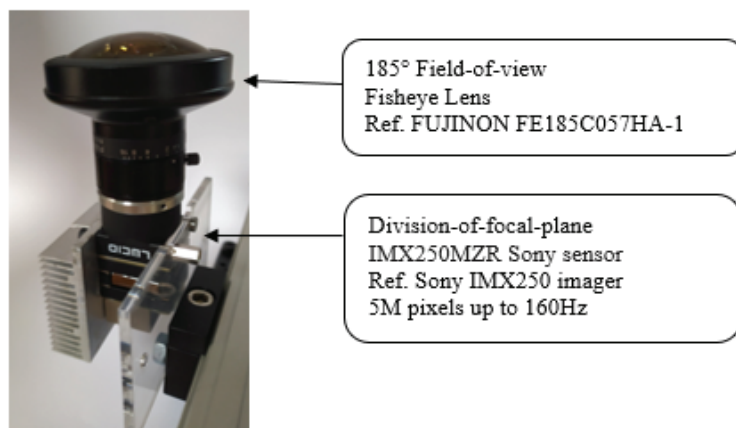


Fig. 1: A micro polarizer camera fitted with a fisheye lens.

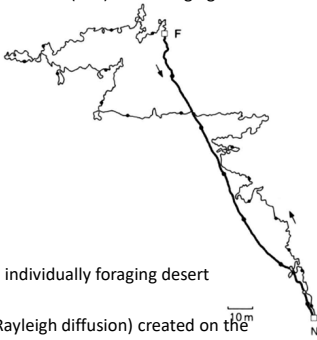
- [1]. Lambrinos, D., Kobayashi, H., Pfeifer, R., Maris, M., Labhart, T., & Wehner, R. (1997). An autonomous agent navigating with a polarized light compass. *Adaptive Behavior*, 6(1), 131-161.
- [2]. He, X., Zhang, L., Fan, C., Wang, M. & Wu, W. (2019). A MIMU/Polarized Camera/GNSS Integrated Navigation Algorithm for UAV Application. In: *2019 DGON Inertial Sensors and Systems (ISS)*, IEEE, 1–15
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Previous works in the lab : a bio-inspired approach to mimic *Cataglyphis* ant's navigation methods

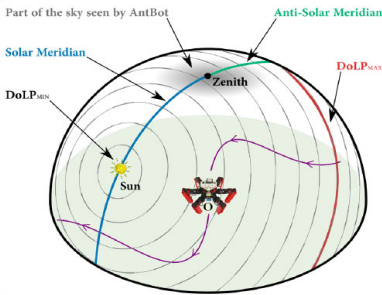
Desert Ants navigate and find their way back home ("N") after foraging in search for food ("F")



Outward and homeward paths of an individually foraging desert ant, *Cataglyphis fortis*. From [5]

→ Use of Skylight polarization pattern (Rayleigh diffusion) created on the atmosphere by the Sun's light.

In 2019, Dupeyroux et al. [3][4] made a robot, "AntBot", able to mimic this behavior :



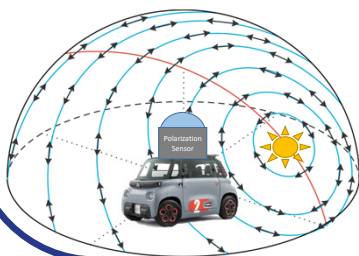
3D diagram of the pattern of polarization in the sky relative to the AntBot robot observer (O), at a given elevation of the Sun. The gray curves give the Angle of Polarization all around the dome of the sky. The minimum Degree of Linear Polarization (DoLP) occurs in the region of the Sun, and the maximum DoLP occurs 90° from the Sun (red curve). From [4]

Can we adapt this work for an automotive application ?

- Development of Autonomous Cars => need for a robust localization system.
 - Global Navigation Satellite Systems (GNSS) have a degraded accuracy in some situations, like near buildings => need for merging several sensors.
- Using Odometer + Heading sensor can provide a different way to get localization [1][2]

Here the goal is to **measure the sun's position** in the sky to get a **known landmark** to obtain vehicle's heading.

As the **sun isn't always directly visible** (clouds, trees, buildings ...), we measure the **polarization pattern** to deduce it.



Goal : Measuring Skylight Polarization to get vehicle's heading

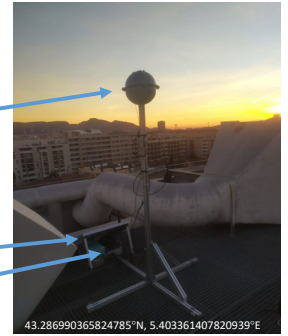
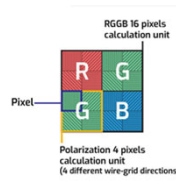


Bio-inspiration

How does the skylight polarization pattern evolve with time & weather degradation ?

→ Design of a long-term measurement device using a **Division-of Focal-Plane (DoFP)** Polarization Imager with integrated micro-polarizers.

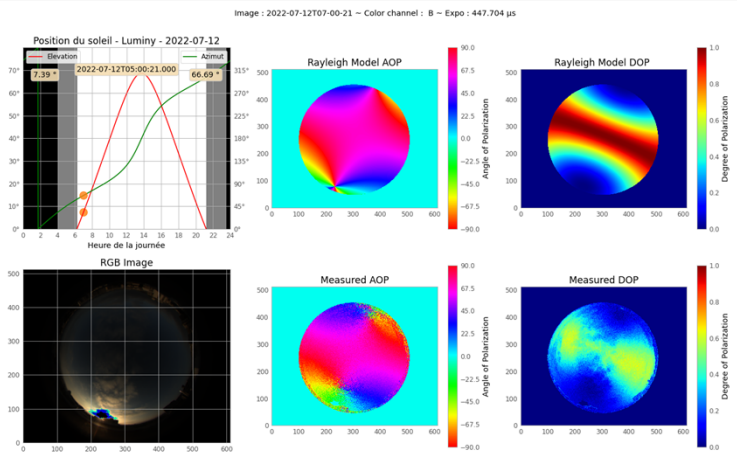
Polarization Camera on rotative mount



Solar Panel

Electronics

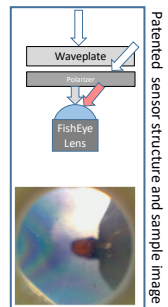
→ A Dataset of Skylight Polarization is acquired. We can compare the Rayleigh Model of the sky (top center/right figure) and our measurements at the same time (bottom), for example here with a cloudy weather :



As real data differs significantly from the simple model, this dataset will be useful to design our skylight polarization sensor. This data will allow us to simulate the response a real sensor would have had if it has been exposed to such weather condition.

→ As **DoFP Cameras** are still too **costly** for mass-market use (~€2,000 / Unit), we are investigating other ways to get heading using a **low-cost consumer-grade camera** instead topped with a waveplate to **spatially encode the polarization information** in interference fringes. The collected skylight data will be useful to simulate the behavior of a sensor in various weather conditions given some fixed optical parameters (waveplate material, thickness, lens field angle ...). This will allow us to find an optimal configuration.

→ A **patent** has been filed about this new kind of sensors [6], and a first prototype have been manufactured with tests ongoing.



- A DoFP camera-based system have been used to generate a long-term dataset about the polarization state of the sky, despite varying weather conditions like clouds.
- This dataset will be much-needed to choose optimal characteristics of a new, low-cost patented sensor : we will evaluate this sensor performance by simulation. Then a new prototype will be built and tested in real outdoor conditions. The final goal is to have an embeddable sensor onboard a car to get dead-reckoning-based localization.

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 * This research was supported by the Openlab "Automotive MotionLab" part of the SteLLab network.