Horizon
The EU Research & Innovation Magazine

European Commission

Dung beetles' inner compass could inspire cutting-edge miniature robotics

Insight into how dung beetles navigate in a straight line is helping EU-funded researchers to design nature-inspired technology and to understand how light pollution affects wildlife.

29 October 2026 - By GARETH WILLMER

When a humble dung beetle arrives at a patch of manure, it forms the dung into a ball and rolls it away in a straight line, putting distance between its food and competitors. That may sound simple, but there is much more to it than meets the eye.

Lost in a desert at night or in a dense forest, people usually struggle to maintain a straight course and can easily end up walking in circles. Dung beetles, by contrast, can travel in remarkably straight lines, thanks to a sophisticated navigation system packed into a brain smaller than a grain of rice. Before setting off, they pirouette on top of the dung ball, taking a visual "snapshot" of the sky above them before rolling their prize backwards with their powerful hind legs.

"There can be thousands of beetles arriving on one dung patch during periods of high competition," said Professor Marie Dacke, a sensory biologist at Lund University in Sweden. "By moving perfectly straight, they can maximise the distance between themselves, other beetles and the dung pat with every step they take."

Apart from advancing our understanding of animal behaviour, this remarkable ability could inspire more efficient navigation systems for autonomous robots, drones, driverless cars and technologies operating in challenging environments.

Cue selection

Dacke set out to investigate this ability in the EU-funded UltimateCOMPASS initiative, which she led for six years until May 2025. “My aim has been to understand how biological compasses can work in any environment at any time,” said Dacke.

One advantage of studying dung beetles, she explained, is that they are active both by day and night, and live in diverse environments ranging from dense forests to deserts and savannahs.

Different insects were already known to use different cues, such as the position of the sun, moon, stars and Milky Way, as well as the direction of the wind, to navigate. But understanding how they balance these cues as conditions change has proved more complicated.

To help understand this, Dacke’s team carried out experiments in both the lab and the field. They used mirrors to manipulate the sun’s position and fans to simulate wind direction and speed, isolating the influence of different cues.

The experiments showed that the beetles dynamically changed how much they relied on wind and sun at different times. They appeared to use both simultaneously rather than switching between them. The higher the sun was in the sky, the more the beetles tended to rely on the wind, suggesting that they adjust the relative importance of each cue as conditions change.

Seizing the moment

“The dung beetles respond from moment to moment to how the environment is changing,” said Dacke. “The way they so quickly adapt their whole compass system to the world around them holds the secret to why they can orient by night and day, and at times of high and low solar elevation.”

The researchers also found that, at night, dung beetles use patterns of polarised light around the Moon. Their eyes contain receptors sensitive to the green wavelengths available under moonlight.

The team also studied beetles that repeatedly travel between a dung pile and a burrow. To investigate how they remember how far to go and in what direction, the researchers cooled them on ice to induce anaesthesia and disrupt neural activity. These insects still moved in the expected direction, but had forgotten the distance they should travel, offering clues about the role of memory in navigation.

Dacke’s team inserted tiny electrodes into individual neurons in dung beetles’ brains to track their activity and connections. By doing so, they obtained the first brain recordings relating to the internal compass of freely orienting dung beetles.

Mixing nature and tech

Professor Barbara Webb, a biorobotics researcher who runs the Insect Robotics Group at the University of Edinburgh and also worked on UltimateCOMPASS, explained how such findings can be applied to robotics and alternative navigation and compass systems.

“Insects can do some things that robots are not very good at,” said Webb. “If we can understand how they can do those things, we might be able to come up with some effective solutions for robotics.” Conversely, she said, researchers can test whether they understand insect behaviour properly by seeing whether robots modelled on it behave as expected.

She explained that her team had used Dacke's and others' findings about the dung beetle's brain to design a tiny neural circuit for a robot. They then tested whether the robot could replicate the insect's movements when exposed to different strengths, elevations and directions of sunlight and wind. The robot performed broadly in the same way, she said.

"The insects are solving navigational problems with tiny neural networks," said Webb. "It shows that these things can be done in a super-efficient way with very low energy consumption."

She said findings on insects could be applied to nature-inspired compass systems that act as a backup if GPS fails, including for activities in areas such as agriculture.

"What I'd like to see is small, simple, efficient robots for different contexts," said Webb. "One application area is in precision agriculture, helping, for example, to deliver pesticides only to an area of a field where they are needed, rather than spraying the whole field."

Artificial light effects

Apart from robotics, UltimateCOMPASS provided important evidence on how insects are affected by light pollution. Artificial light interfered with the beetles' use of natural signals in the sky, affecting their ability to navigate normally and drawing them towards artificial light sources. This increased competition between them and reduced their ability to spread out and avoid one another.

"By understanding how light pollution affects navigating fauna, we can provide information for people designing lights in cities to reduce the effect on animals," said Dacke.

She is now investigating in more depth how dung beetles integrate different inputs, including exactly how their initial pirouette on the dung ball calibrates their navigation. This could reveal more of nature's solutions to problems that engineers are trying to solve.

"Through our research, I want to show how remarkable the solutions are that nature has found to challenges around us," she said.

Research in this article was partly funded by the European Research Council (ERC). The views of the interviewees don't necessarily reflect those of the European Commission. If you liked this article, please consider sharing it on social media.

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- UltimateCOMPASS (CORDIS)
- UltimateCOMPASS project website
- Stars and inner compass guide moths and birds, say researchers