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Neural models of ant navigation in a realistic 3D world

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Introduction

- Desert ants store memories of views when traversing a route. Later, they can recover the correct heading direction on the route by comparing the current view with views stored in their memory.
- Here we use ecologically relevant data to test a computational model of view memory in the insect's mushroom body.
- Data collected in field experiments is used to reconstruct a realistic 3D virtual environment, including ground surface, vegetation and the full sky polarization pattern.
- The virtual world allows simulation of realistic visual inputs based on an ant-eye model, including UV-green vision.
- We use the virtual world to test the efficacy of the mushroom body model, and compare its output to simple root mean square (RMS) image comparison.
- We also measure the impact of parameters such as the tilting and pitching caused by travel over uneven ground, and the amount of vegetation in the view.

Materials and Methods

The agent

The mushroom body model

The proposed neural circuit (Ardin et al. 2016) can store snapshots of views, allowing the familiarity of a presented view to be computed (see figure below). From left to right:

Input: Snapshots from the 3D simulation are normalized by each colour channel.

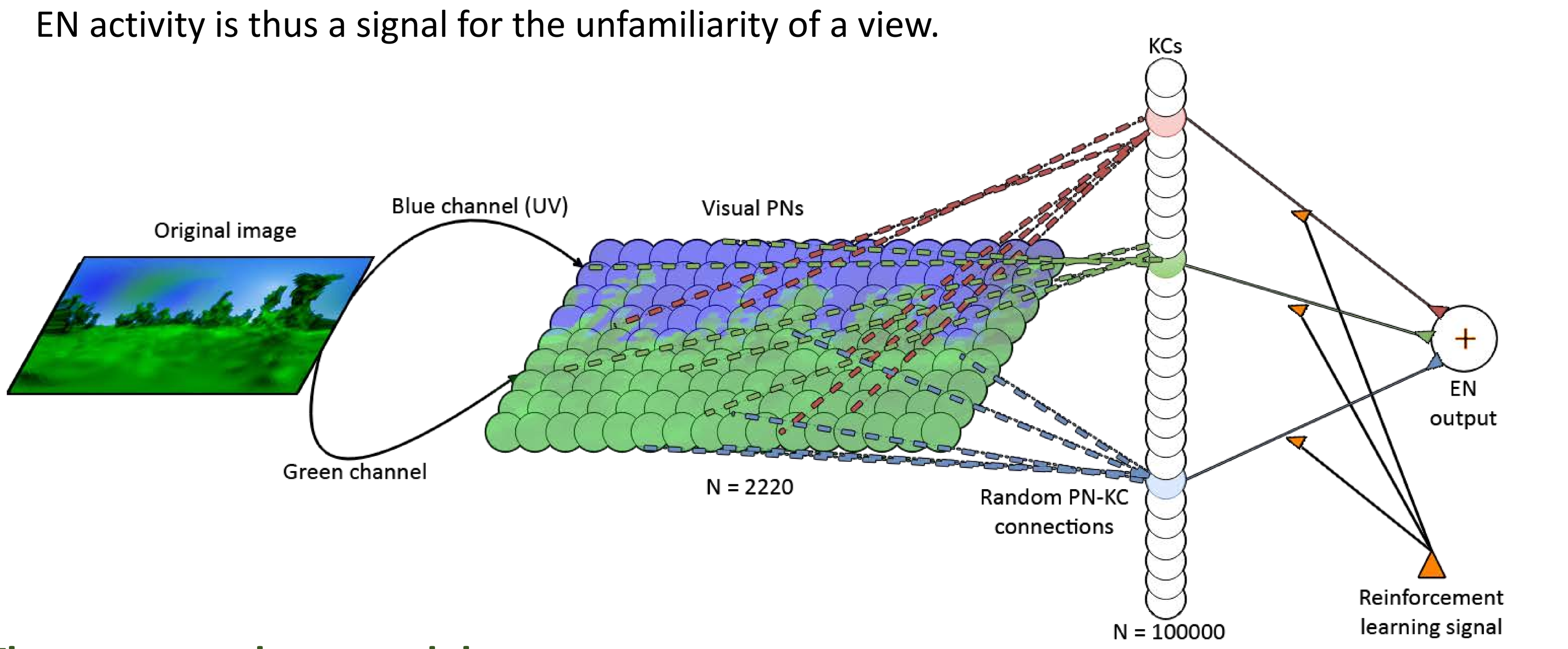
Layer 1: 2,220 visual Projection Neurons (PNs) convey a low resolution image to the next layer.

Layer 2: 100,000 Kenyon Cells (KCs).

- Each KC obtains input from 10 PNs (random connections).
- The KCs will have a sparse activation pattern, specific to each image.

Layer 3: A single Extrinsic Neuron (EN) sums the KCs output.

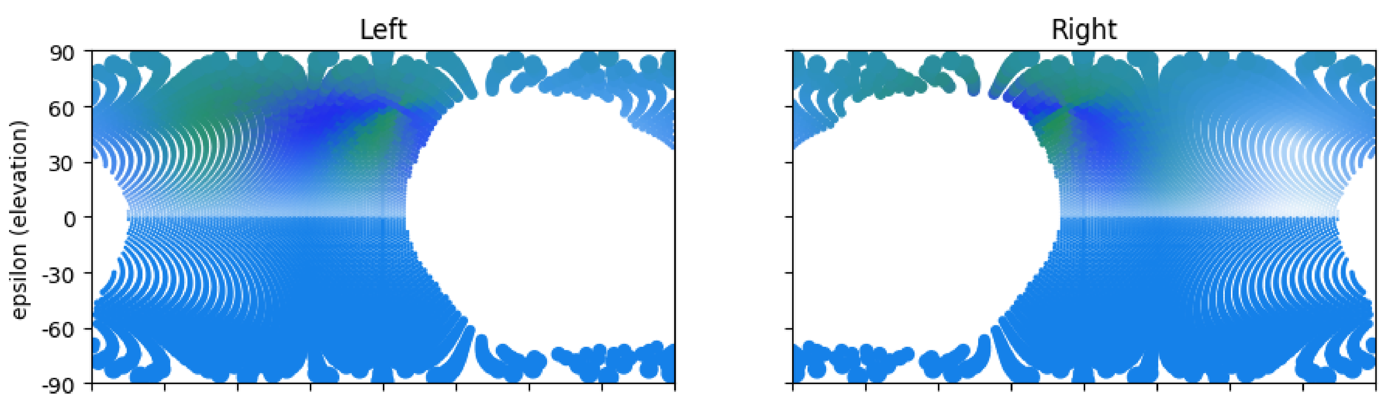
- Weights between the active KC and EN are decreased when there is a reinforcement signal.
- Subsequent activation with the same input produces a lower EN output.
- EN activity is thus a signal for the unfamiliarity of a view.



The compound eye model

- Based on the bee compound eye computational model described in Stürzl et al. (2010).
- Acceptance angles and estimated distribution of the ommatidia for the DA, DRA and VA eye regions are taken from the desert ant eye measurements in Labhart (1985).

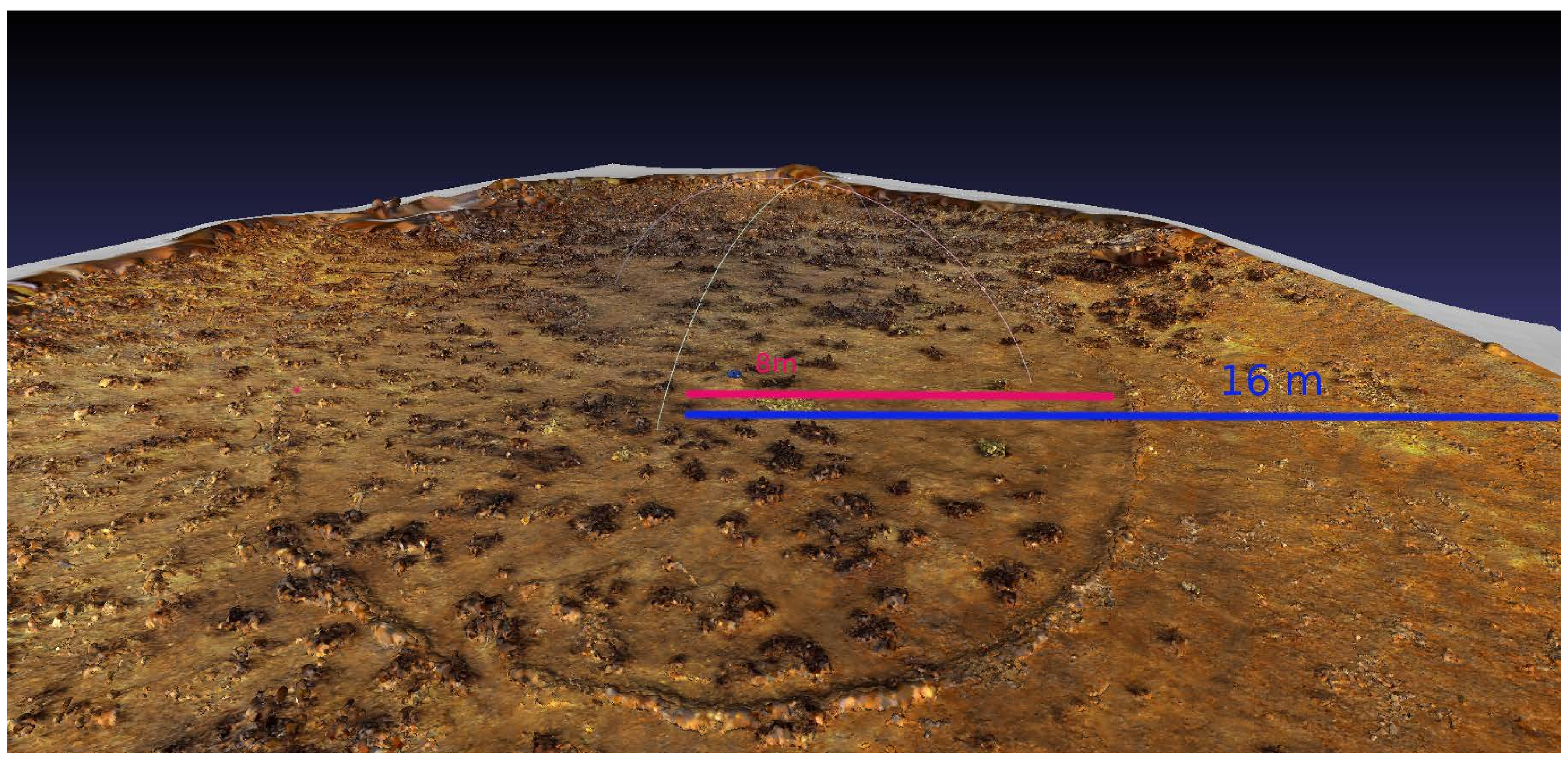
Ommatidia distribution for the left and right compound eye in the simulated ant vision model (280° FOV). Each eye has 1110 ommatidia.



The environment

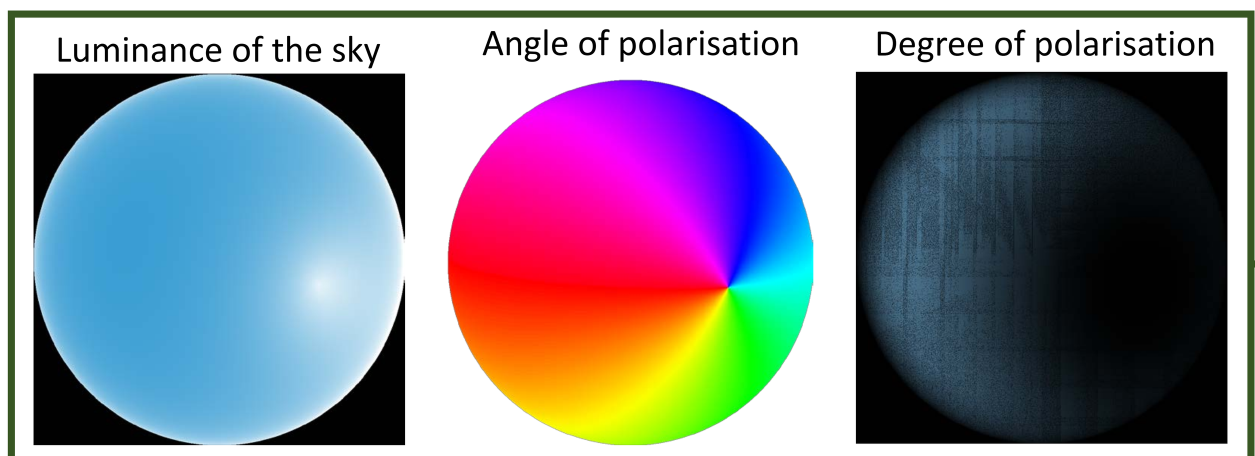
The ground and vegetation

Top view of the simulated 3D environment, reconstructed from LIDAR scans of our ant field site near Seville. It includes uneven ground and cluttered vegetation.

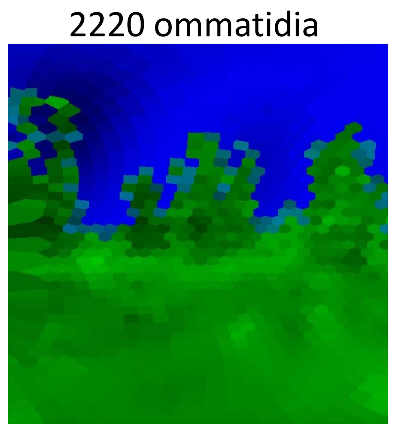


The sky polarisation pattern

We simulate the sky luminance, and the angle and degree of polarisation, given a specific solar elevation and azimuth based on the analytical models of Wilkie et al. (2004) and Perez et al. (1994).



Screenshot of the simulation Green (ground) and UV (sky) 2220 ommatidia



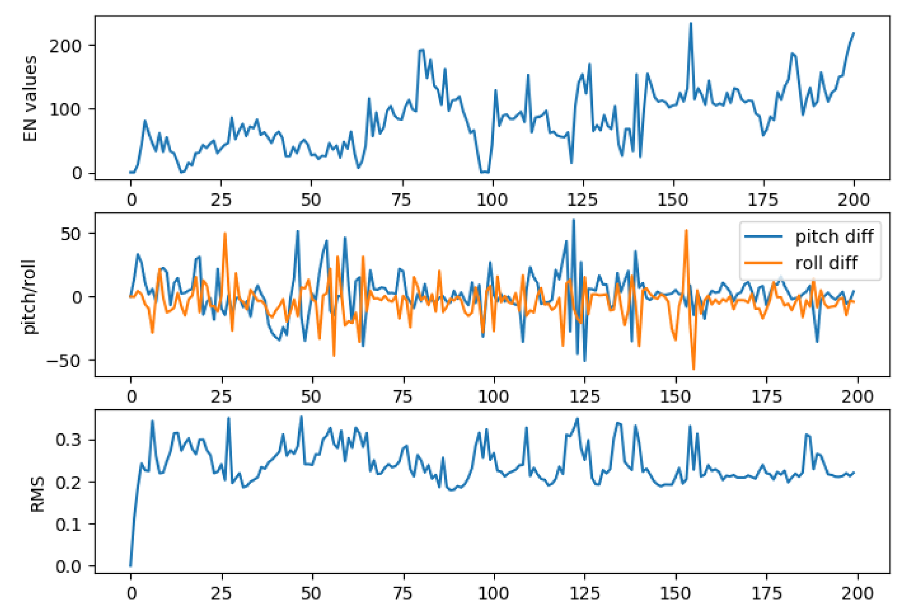
Results

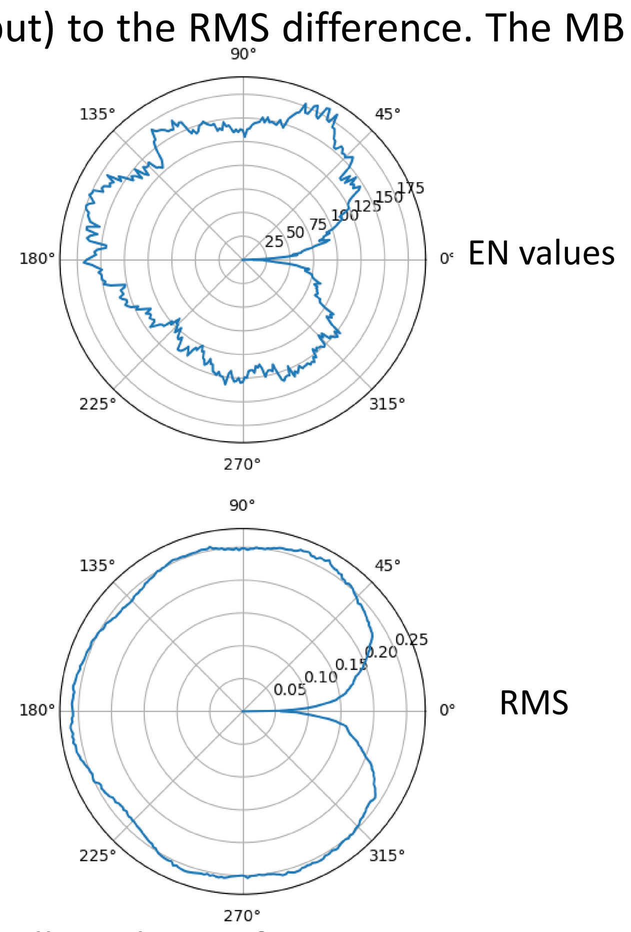
The MB model performance vs RMS difference

Testing in the 3D cluttered environment:

1) A snapshot at a specific location is stored, and then compared to views facing this location from up to 200cms away, in 1cm steps. This includes pitch and roll from uneven terrain.
2) The same snapshot is compared with images taken while yawing on the spot (359 images, 1 degree turn), without pitch and roll.

For each we compare the results of the MB model (the EN output) to the RMS difference. The MB output shows a more gradual change with distance.

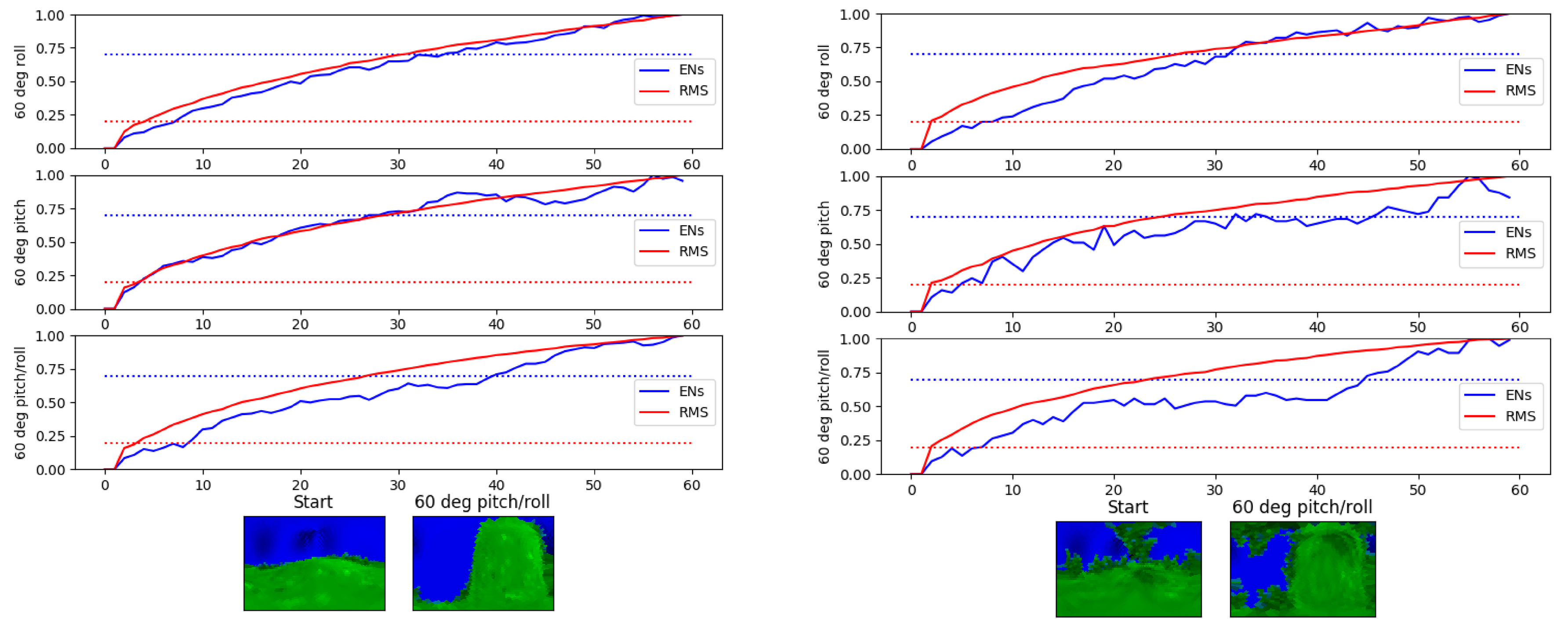


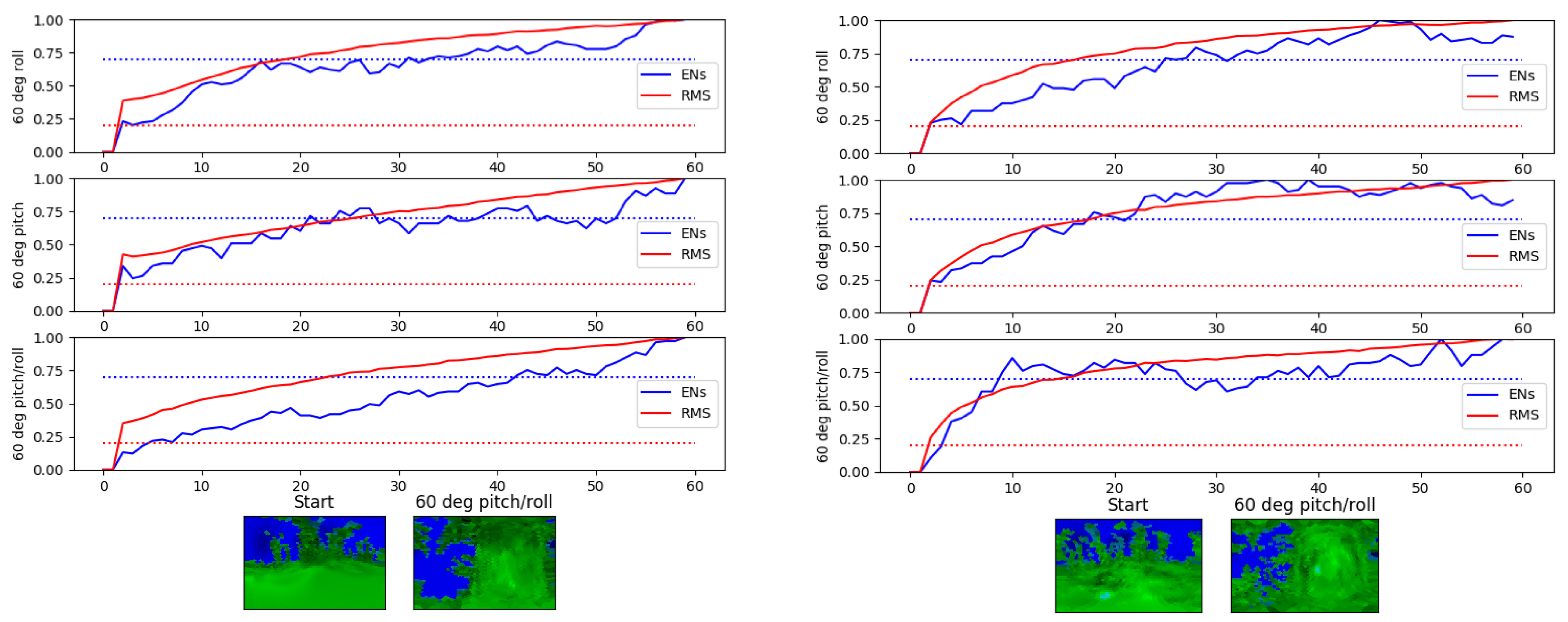


To further analyse the effects of pitch and roll:

1) We picked 4 locations with increasing level of vegetation.
2) We evaluated the effect of 60 degrees pitch, roll and pitch/roll on the performance.

Results show that the presence of vegetation helps the MB model improve its robustness against pitch and roll variations.



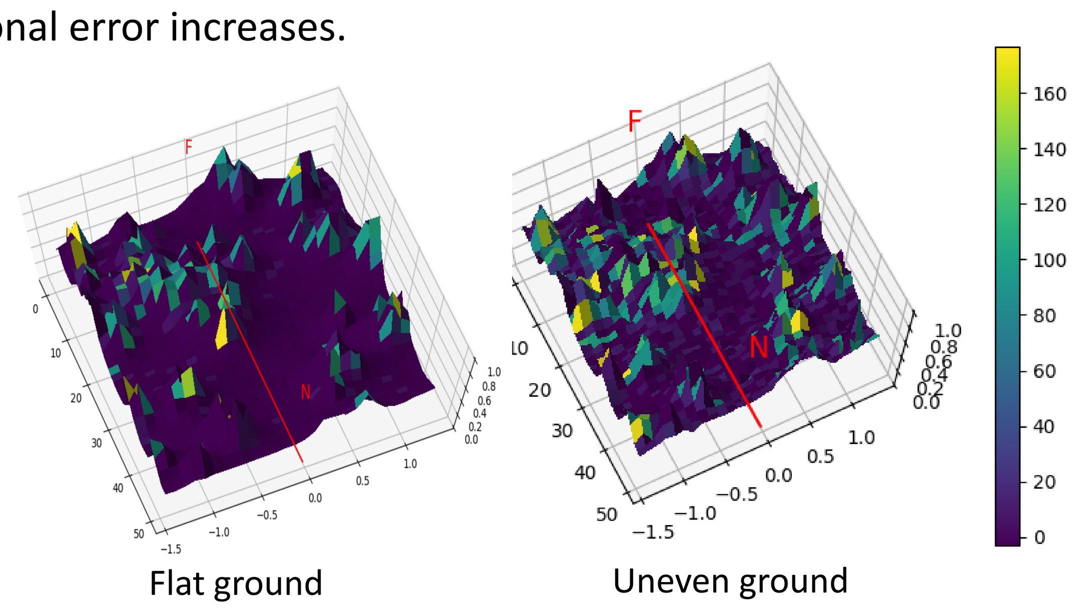


We finally evaluated the effect of the sky/vegetation ratio for each image on the model performance.

1) The MB model was trained to learn a full straight route from a feeder (F) to a nest (N) storing snapshots every 10cm.
2) The ability to recall the correct heading direction to the nest was measured on the same route and on 28 parallel routes at 10cm distances, covering an area from -1.5m to 1.5m.

The directional error (the difference between the correct angle and the chosen angle) for each location is shown below for both uneven ground and flat ground. In both cases, when the sky ratio increases too suddenly, the directional error increases.

Performance of the model in recalling the correct heading direction on the main learned route and on the 28 parallel routes for both even and uneven ground. The z axis shows the sky/vegetation ratio while the colour indicates the directional error.



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