From Rats to Robots: Bio-inspired Localization and Navigation

Gordon Wyeth, Michael Milford, Will Maddern
Neural Encoding of Space

Firing rates of neural units are measured with respect to the position in the arena and the absolute bearing of the head.
Cells That Encode Space

(a) Place cell
(b) Head direction cell
(c) Grid cell
(d) Conjunctive grid cell
Rat Brains Track Pose

• The rat’s brain maintains a *code* that describes rat’s global pose in three degrees of freedom \((x, y, \theta)\). The code is:
  1. Maintained in absence of sensory input.
  2. Updated from odometric input.
  3. Corrected by distinctive sensory input.
Wiring Diagram of a Rat Brain

- Landmark Cues
- Place Cells
- Grid Cells
- Head Direction Cells
- Self-Motion Cues
- Action

Legend:
- 90°, 180°, 270°, 0°
- 10 Hz, 5 Hz
Computational Model of a Head Direction Network
Maintaining Head Direction

0° 30° 60° 90° 120° 150° 180° 210° 240° 270° 300° 330°
Applying Odometry to Update Head Direction

Nolan C., Wyeth G., Milford M. and Wiles J. “The race to learn: spike timing and neuromodulation can coordinate learning and recall in CA3”, Hippocampus, March 2010
Calibration by Landmarks

Boundary Problem

(McNaughton, 2006)
Torus Attractor “Recording”

- Similar to tesselations seen in grid cell recordings.
RatSLAM

Experience Map

Grid Cells

Pose Cells

Landmark Cues

Self-Motion Cues

Head Direction Cells

Action
RatSLAM Model

RatSLAM

Experience Map

Landmark Cues

Pose Cells

Self-Motion Cues

Locally consistent spatial code

Action
3D Attractor - Pose Cells

Pose Cells are like Grid Cells

Cells have similar functional characteristics (reset to landmarks, track self motion) and similar connectivity (local excitation, broad inhibition).

Hafting, T. *et al.*, 2005

RatSLAM Model

RatSLAM

Experience Map

Landmark Cues

Visual data association

Pose Cells

Self-Motion Cues

Action
Visual Data Association

LV2

LV1

LV3

LV4

Pose cells

Pose cells
RatSLAM Model

RatSLAM

Experience Map

Action

Landmark Cues

Pose Cells

Self-Motion Cues
Experience Map Example

a unique combination of landmark cues and pose code.
Mapping a Suburb

- Mapped the entire suburb of St. Lucia from 100 minutes of webcam video.

Office Delivery Challenge

• The robot started “out of the box” in an unknown office and laboratory complex.
• 1000 “deliveries” made over a two week period at all times of night and day.
• The robot maintained it batteries by locating and docking with its charger.
• Kidnapped the robot to another unknown office and laboratory complex.
Office Delivery Key Results

• 1177/1178 successful deliveries / recharges.
• Maintained minimum delivery times over the two week period.
• Negligible growth in space and computation requirements after initial exploration.
• Robot recovered robustly from kidnapping.

The Down Side ...

- Rat-SLAM relies on 20+ parameters (magic numbers) to work effectively
- Many parameters are unit-less and empirically chosen
- No engineering basis for setting parameters
CAT-SLAM

• **Continuous Appearance-based Trajectory SLAM**

• Replaces the neural mechanisms for pose filtering and pose-view association with probabilistic mechanisms.

• No magic numbers!
Creating a Trajectory
Updating the Place Hypothesis
Incorporating Visual Information

Good Match

Reference Image
Shop
Fence
Stop Sign

Current Image
Shop
Fence
House

Reference Image
Tree
Fence
House
Incorporating Visual Information

Reference Image

Shop
Fence
Stop Sign

Current Image

Flowers
Grass
Road

Reference Image

Tree
Fence
House

Poor Match
Removing Redundant Information

Reference Image

Tree
Fence
House

Reference Image

Tree
Fence
House

Reference Image

Tree
Fence
House
Experimental Setup – New College

- 2.25km tour of Oxford New College
- Ladybug2 panoramic camera
- Odometry from shaft encoders on Segway platform
- GPS ground truth
- Results compared to FAB-MAP

Results: Precision-Recall

CAT-Graph

- CAT-SLAM develops a trajectory - a set of points over time.
  - Not suitable for many revisits to the same location
  - Not suitable for path planning.
- By introducing one parameter for certainty required for loop closure, we can form a graph rather than a trajectory.
Creating a Graph
Creating a Graph
Experimental Setup: S Block QUT

- 7 routes through S Block Level 7 over a week
- CAT-Graph with 2000 particles, 5000 nodes
- openFABMAP
- Metric ground truth from laser scanner


Experimental Setup: S Block QUT
Results: Loop Closure Distribution

Results: Loop Closure Distribution

Results: Loop Closure Distribution

Results: Loop Closure Distribution

Results: Precision-Recall

Conclusions

• Understanding the biological basis of rodent navigation created a highly competent robot navigation system – RatSLAM.

• CAT-SLAM and CAT-Graph are a further evolution of RatSLAM that are more applicable to engineering applications.