Terrain Navigation
Using the Ambient Magnetic Field as a Map

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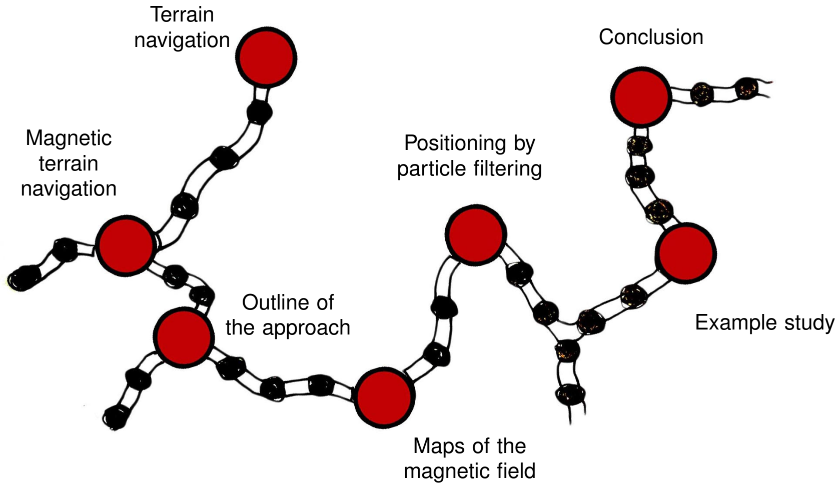
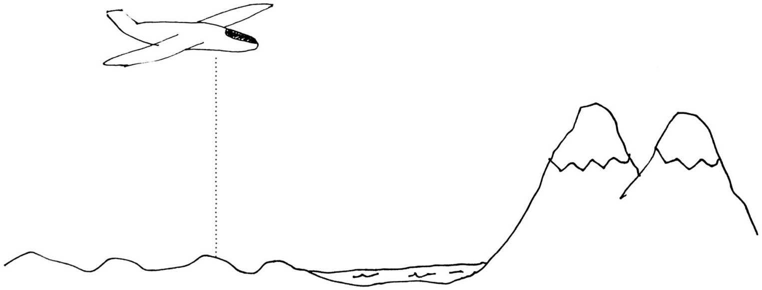
Presentation Outline



(Classical) Terrain Navigation



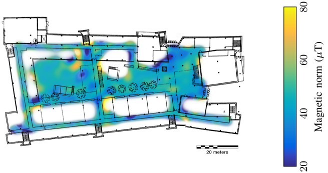
Terrain Matching in the Magnetic Landscape

Outline of the Approach

- **Magnetic terrain map**:
  A Gaussian process model for the magnetic field estimate and its variance for any spatial location in the building.
- **Particle filtering**:
  A sequential Monte Carlo approach for proposing different state histories and finding which one matches the data the best.
- **Pedestrian dead reckoning**:
  A model for the movement of the person being tracked.

Maps of the Magnetic Field

- A map of the magnetic field is required.
- The magnetic field is a vector field.
- A set of measurements of the magnetic field at known spatial points.
- Interpolation and extrapolation of the magnetic field done by a Gaussian process (GP) regression model [1].
- The model combines the noisy measurements with prior information from the physical properties of magnetic fields.
- The output is both the mean and marginal variance of the magnetic field at any spatial input.



Magnitude of the magnetic field.

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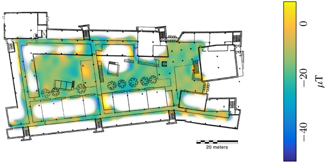
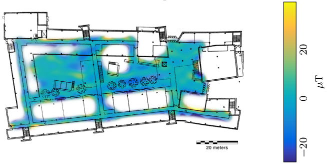
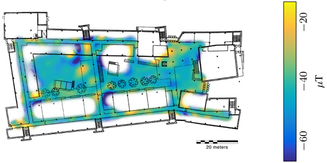


(a) x-component



(b) y-component



(c) z-component

Positioning by Particle Filtering

- Probabilistic statistical inference on where the user is based on his/her history of magnetometer observations.
- Concerned with state space models of form

$$\mathbf{x}_{k+1} \sim p(\mathbf{x}_{k+1} \mid \mathbf{x}_k),$$
$$\mathbf{y}_k \sim p(\mathbf{y}_k \mid \mathbf{x}_k).$$

- State variables: user position and heading angle.
- Combining assumptions of user movement (PDR) and ...
- ... how the assumed positions match the magnetic field.

Positioning by Particle Filtering

Initialization: Draw n samples from the prior $\mathbf{x}_0^{(i)} \sim p(\mathbf{x}_0)$, $i = 1, \ldots, n$.

For each time step $k = 1, 2, \ldots$

1. **Prediction**: Draw samples $\mathbf{x}_k^{(i)}$ from the importance distributions

$$\mathbf{x}_k^{(i)} \sim \pi(\mathbf{x}_k \mid \mathbf{x}_{k-1}^{(i)}, \mathbf{y}_{1:k}), \qquad i = 1, 2, \ldots, n.$$

   This propagates the particles according to the PDR model.

2. **Map matching**: Calculate new weights according to

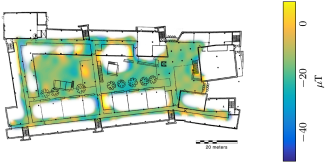
$$w_k^{(i)} \propto w_{k-1}^{(i)} \frac{p(\mathbf{y}_k \mid \mathbf{x}_k^{(i)})\, p(\mathbf{x}_k^{(i)} \mid \mathbf{x}_{k-1}^{(i)})}{\pi(\mathbf{x}_k^{(i)} \mid \mathbf{x}_{k-1}^{(i)}, \mathbf{y}_{1:k})}$$

   and normalize them to sum to unity.

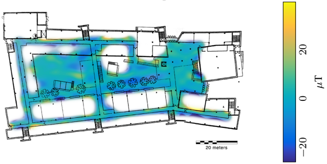
3. **Resampling**

Example Study

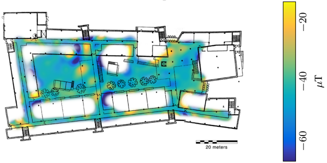
- Case study:
  - CS Building at Aalto University.
- Mapping:
  - Nexus 5 smartphone.
  - 867 m of mapping paths in 15 min.
  - Some 42 000 measurements.
- Test paths:
  - Collected two weeks later.
  - Sampling rate in the test paths is 5 Hz.
  - Each test case roughly 30 s long.
  - 100 test paths altogether.
- Setup:
  - Particles $n = 5000$.
  - Sensors calibrated off-line.



(a) x-component

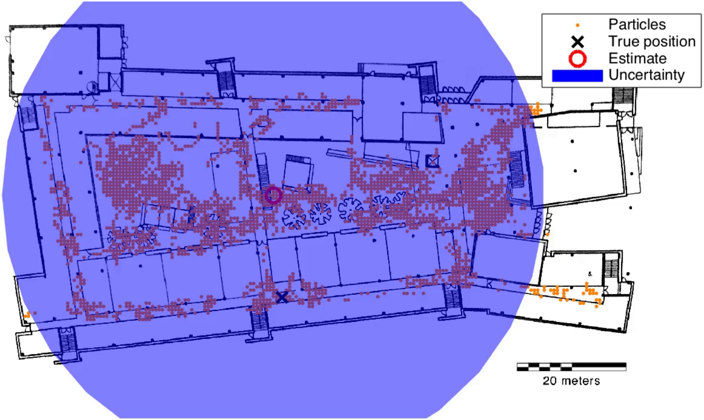


(b) y-component



(c) z-component

Example Study



The videos are available on YouTube:

`https://youtu.be/UuUo9QOOT1Q`

Conclusion

- Good performance even using magnetic only:
  - Time-to-convergence: 12 s.
  - Distance-to-convergence: 13 m.
  - Error after convergence: 5 m (best case 1–2 m.).
- What to do to take this further:
  - Sensor calibration.
  - Pedestrian dead-reckoning.
  - Further sensor fusion (satellite and radio).
  - SLAM.

Bibliography

[1] Arno Solin, Manon Kok, Niklas Wahlström, Thomas B. Schön, and Simo Särkkä. *Modeling and interpolation of the ambient magnetic field by Gaussian processes*. Accepted for publication in IEEE Transactions on Robotics.

[2] Arno Solin, Simo Särkkä, Juho Kannala, and Esa Rahtu (2016). *Terrain navigation in the magnetic landscape: Particle filtering for indoor positioning*. Proceedings of the European Navigation Conference.

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