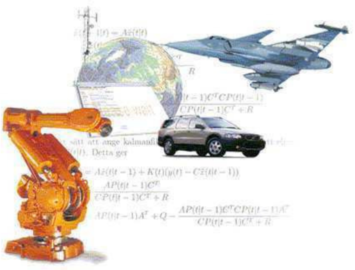
Rapid Classification of Vehicle Heading Direction with Two-Axis Magnetometer



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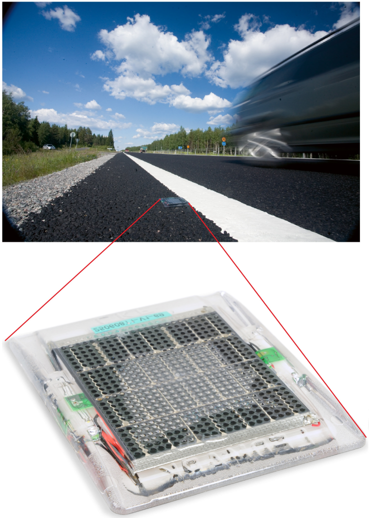
Background



Traffic monitoring in wireless sensor network

- Sensor nodes equipped with a magnetometer.

Limitations:

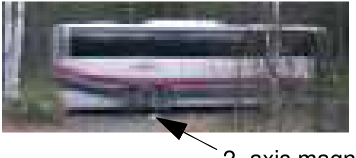
- Energy budget
- Computational resources.

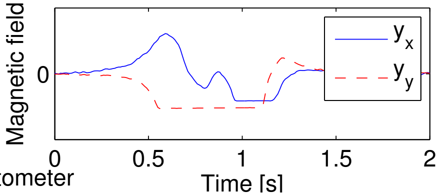
Information you can extract

- Number of vehicles
- Type of vehicle
- *Heading direction*

Problem formulation

- 2-axis magnetometer has been deployed on the roadside





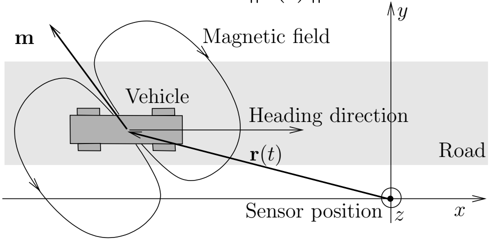
- Magnetometer measures a distortion of the magnetic field.

We want to classify the heading direction of the vehicle!

Magnetic dipole

The vehicle can be modeled as a magnetic dipole:

$$\mathbf{h}(t) = \frac{3(\mathbf{r}(t) \cdot \mathbf{m})\mathbf{r}(t) - \|\mathbf{r}(t)\|^2 \mathbf{m}}{\|\mathbf{r}(t)\|^5}$$

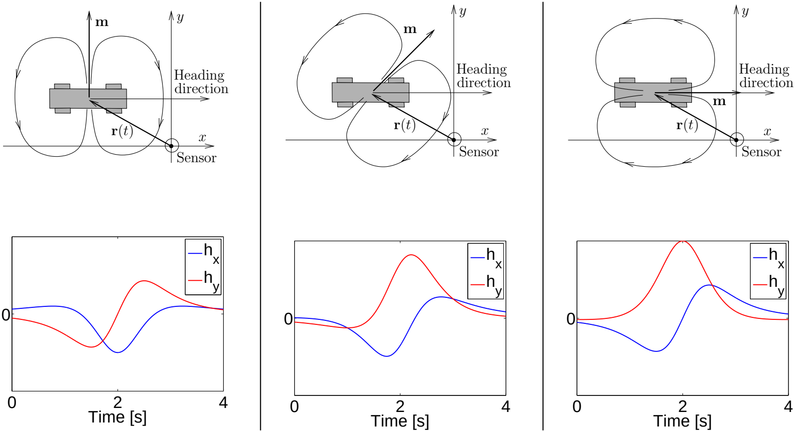


We measure two components of the magnetic field.

$$\mathbf{y}(kT) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \mathbf{h}(kT) + \mathbf{e}(kT), \quad k = 1, \cdots, N$$

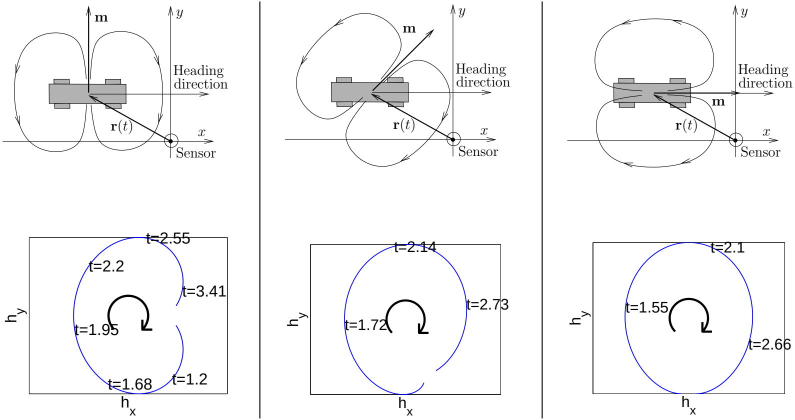
Simulated examples

Three different vehicle are heading in positive x-direction



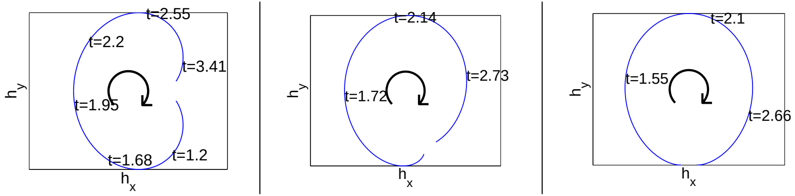
Simulated examples

Three different vehicle are heading in positive x-direction



- All measurement trajectories are turning clockwise!

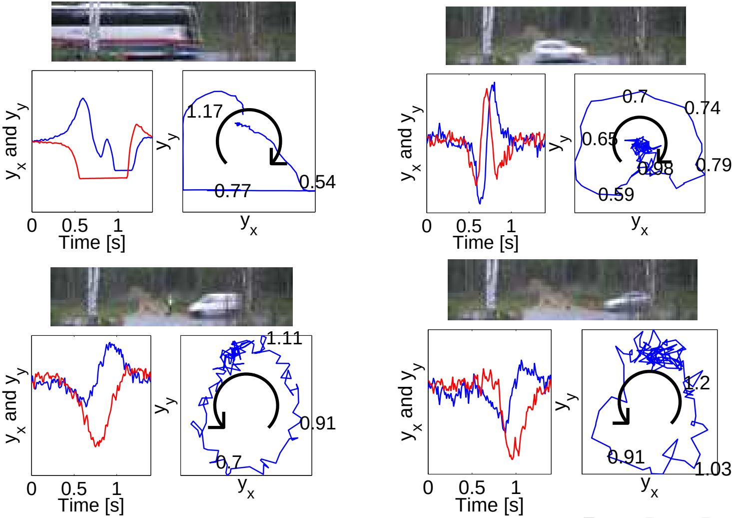
Key idea



Idea:

Classify heading direction by the turn of the measurement trajectory!

Real world data



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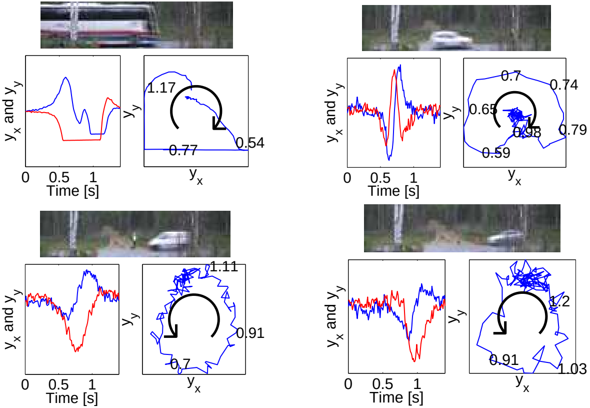
Real world data



Classify driving direction by the turn of the measurement trajectory!

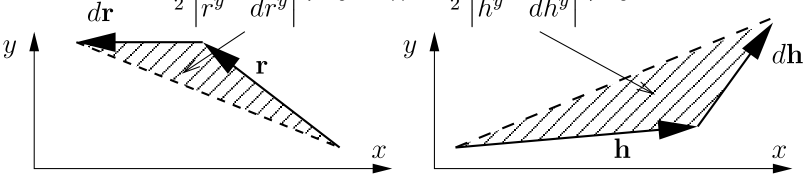
The theorem

Assume the magnetic dipole model

$$\mathbf{h} = \frac{3(\mathbf{r} \cdot \mathbf{m})\mathbf{r} - \|\mathbf{r}\|^2 \mathbf{m}}{\|\mathbf{r}\|^5}$$

then

$$\frac{1}{2}\begin{vmatrix} r^x & dr^x \\ r^y & dr^y \end{vmatrix} > 0 \quad \Leftrightarrow \quad \frac{1}{2}\begin{vmatrix} h^x & dh^x \\ h^y & dh^y \end{vmatrix} > 0$$



Observe: Independent of $\mathbf{m}$!

The classifier

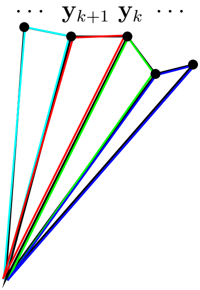
Integrate over all infinitesimal area segments

$$f = \int \begin{vmatrix} h^x & dh^x \\ h^y & dh^y \end{vmatrix} = \int \begin{vmatrix} h^x(t) & dh^x(t)/dt \\ h^y(t) & dh^y(t)/dt \end{vmatrix} dt.$$

The time discrete version will then be

$$\begin{aligned} f =& \sum_{k=1}^{N-1} \begin{vmatrix} h_k^x & (h_{k+1}^x - h_k^x)/T \\ h_k^y & (h_{k+1}^y - h_k^y)/T \end{vmatrix} T \\ =& \sum_{k=1}^{N-1} (h_k^x h_{k+1}^y - h_k^y h_{k+1}^x) \\ =& (\mathbf{h}_{1:(N-1)}^x)^T \mathbf{h}_{(1+1):N}^y - (\mathbf{h}_{1:(N-1)}^y)^T \mathbf{h}_{(1+1):N}^x \end{aligned}$$

The classifier



- Sum over all triangles
- The enclosed area can be computed as two inner products!

$$\hat{f} = (\mathbf{y}^x_{1:(N-1)})^T \mathbf{y}^y_{(1+1):N} - (\mathbf{y}^y_{1:(N-1)})^T \mathbf{y}^x_{(1+1):N}$$

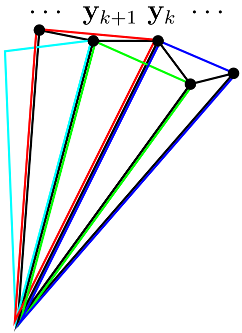
- The sign of $\hat{f}$ determines the heading direction.

Note: $\mathbf{h}$ has been replaced with the measurement $\mathbf{y}$ which contains noise.

The improved classifier

The variance of $\hat{f}$ can be reduced by trading for some bias.

- Idea: Average over larger triangles!

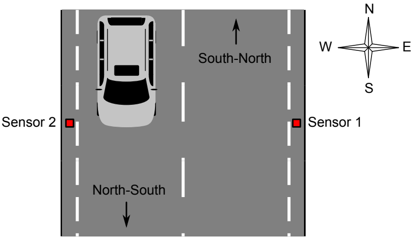


$$\hat{f}_p = (\mathbf{y}^x_{1:(N-p)})^T \mathbf{y}^y_{(1+p):N} - (\mathbf{y}^y_{1:(N-p)})^T \mathbf{y}^x_{(1+p):N}$$

Observe: The feature still only consists of two inner products!

Experimental results

- 2 sensor nodes
- 45 min
- 88 vehicles travelling south-north
- 99 vehicles travelling north-south



Correct classification by the two sensors

	South-North (Sensor 1)	North-South (Sensor 2)
Sensor 1	87/88	91/99
Sensor 2	82/88	99/99

Summary

Vehicle heading direction classification using a 2-axis magnetometer.

- A two-fold classification problem.
- One strong feature has been derived and extracted from data.
- It is fast (difference of two inner products)
- Theoretical justification is provided.
- It works on real world data with good results

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$\Longrightarrow$ Fast and accurate classifier for this application!