



HD Map Errors Detection using Smoothing and Multiple Drives

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Outline

- Problem Statement
- Sensor Overview
- Error Detection
- Results



Problem Statement

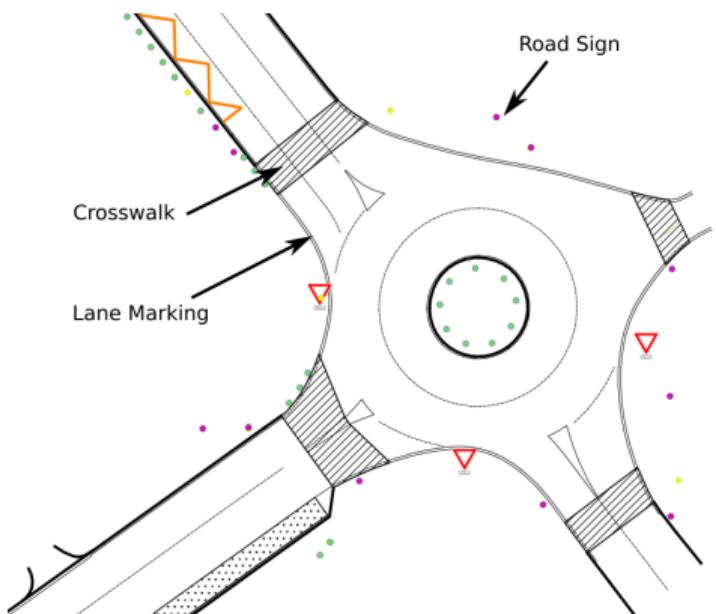
- Map features can change





Sensor Overview

HD Maps

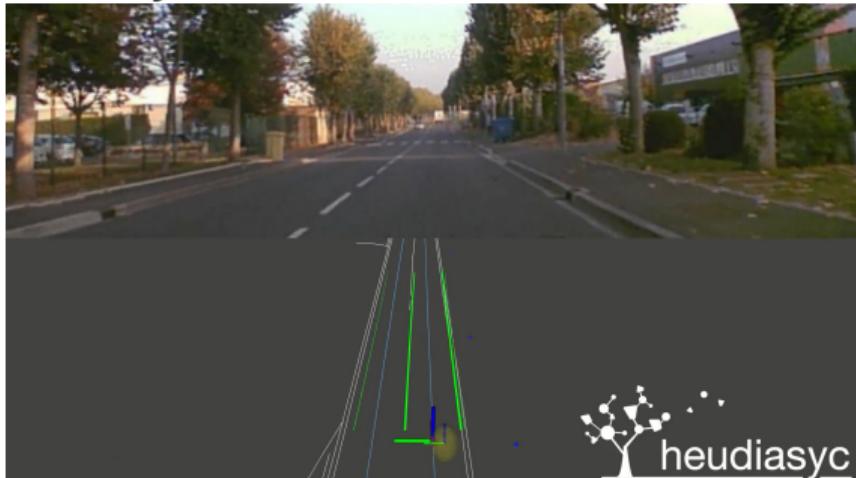




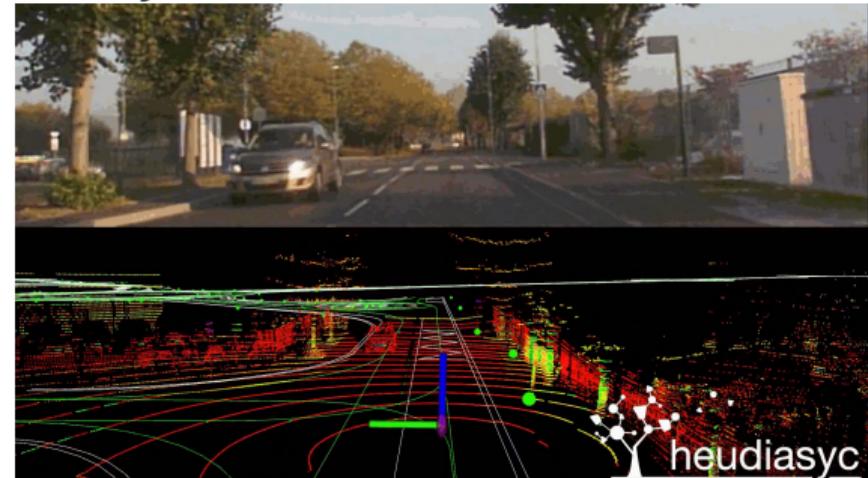
Sensor Overview

Perception Sensors

Mobileye



Velodyne





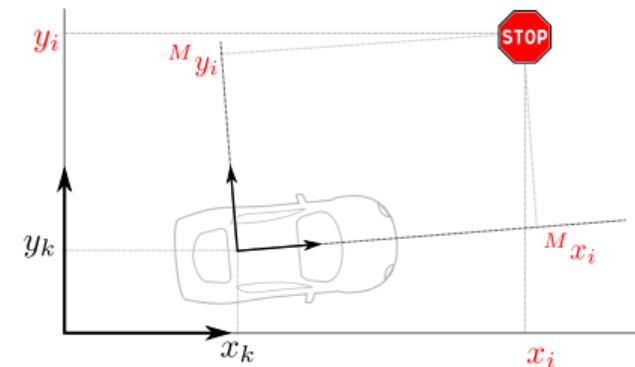
Sensor Overview

Observation Model

Traffic Signs

$$\mathbf{z}_k^j = \begin{bmatrix} x_i \\ y_i \end{bmatrix} = h(\mathbf{x}_k) \quad (1)$$

$$= \begin{bmatrix} \cos \theta_k & -\sin \theta_k \\ \sin \theta_k & \cos \theta_k \end{bmatrix} \begin{bmatrix} {}^M x_k^j \\ {}^M y_k^j \end{bmatrix} + \begin{bmatrix} x_k \\ y_k \end{bmatrix} \quad (2)$$





Error Detection

Kalman Smoothing

$$\hat{\mathbf{x}}_{k|N} = \hat{\mathbf{x}}_{k|k} + \mathbf{J}_k (\hat{\mathbf{x}}_{k+1|N} - \hat{\mathbf{x}}_{k+1|k}) \quad (3)$$

$$\mathbf{P}_{k|N} = \mathbf{P}_{k|k} + \mathbf{J}_k (\mathbf{P}_{k+1|N} - \mathbf{P}_{k+1|k}) \mathbf{J}_k^\top \quad (4)$$

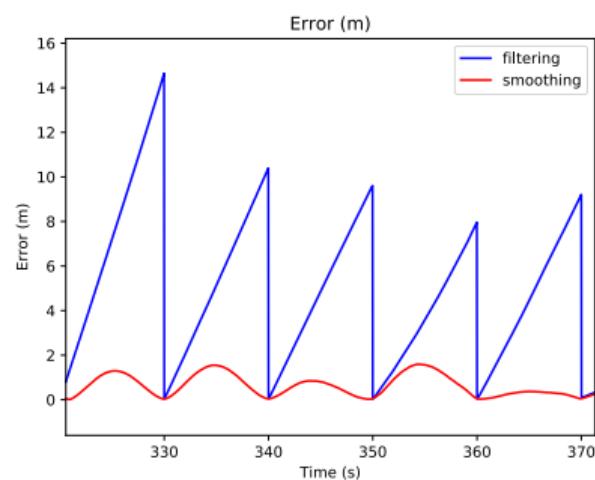
with

$$\mathbf{J}_k = \mathbf{P}_{k|k} \mathbf{F}_{k+1}^\top \mathbf{P}_{k+1|k}^{-1} \quad (5)$$

Post Smoothing Residuals

$$\mathbf{y}_{k|N}^j = \mathbf{z}_k^j - h(\hat{\mathbf{x}}_{k|N}) \quad (6)$$

$$\mathbf{S}_{k|N}^j = \mathbf{R}_k - \mathbf{H}_k \mathbf{P}_{k|N} \mathbf{H}_k^\top \quad (7)$$





Error Detection

Residuals fusion

Single drive (Covariance Intersection)

$$\begin{aligned} \mathbf{S}_i^{-1} &= \omega_{k_0} \mathbf{S}_{k_0}^{-1} + \omega_{k_1} \mathbf{S}_{k_1}^{-1}, \dots, + \omega_{N_i} \mathbf{S}_{N_i}^{-1} \\ \mathbf{y}_i &= \mathbf{S}_i \left(\omega_{k_0} \mathbf{S}_{k_0}^{-1} \mathbf{y}_{k_0} + \omega_{k_1} \mathbf{S}_{k_1}^{-1} \mathbf{y}_{k_1}, \dots, + \omega_{N_i} \mathbf{S}_{N_i}^{-1} \mathbf{y}_{k_{N_i}} \right) \end{aligned} \quad (8)$$



Error Detection

Residuals fusion

Single drive (Covariance Intersection)

$$\mathbf{S}_i^{-1} = \omega_{k_0} \mathbf{S}_{k_0}^{-1} + \omega_{k_1} \mathbf{S}_{k_1}^{-1}, \dots, + \omega_{N_i} \mathbf{S}_{N_i}^{-1} \quad (8)$$

$$\mathbf{y}_i = \mathbf{S}_i \left(\omega_{k_0} \mathbf{S}_{k_0}^{-1} \mathbf{y}_{k_0} + \omega_{k_1} \mathbf{S}_{k_1}^{-1} \mathbf{y}_{k_1}, \dots, + \omega_{N_i} \mathbf{S}_{N_i}^{-1} \mathbf{y}_{k_{N_i}} \right)$$

Multiple drives

$$\bar{\mathbf{y}} \leftarrow \left(\bar{\mathbf{S}}^{-1} + \mathbf{S}^{-1} \right)^{-1} \left(\bar{\mathbf{S}}^{-1} \bar{\mathbf{y}} + \mathbf{S}^{-1} \mathbf{y} \right) \quad (9)$$

$$\bar{\mathbf{S}} \leftarrow \left(\bar{\mathbf{S}}^{-1} + \mathbf{S}^{-1} \right)^{-1} \quad (10)$$



Error Detection

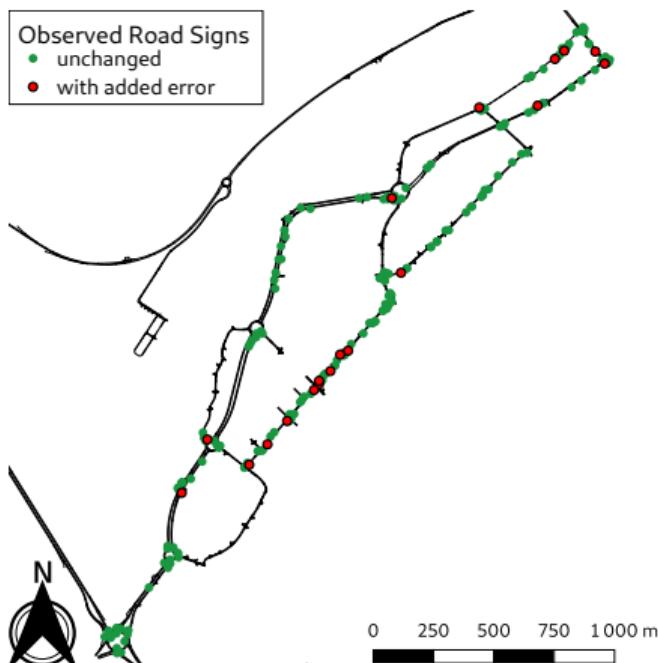
Feature Error Detection

$$\bar{\mathbf{y}} \bar{\mathbf{S}}^{-1} \bar{\mathbf{y}}^T < F_{\chi_2^2}^{-1}(1 - \alpha) \quad (11)$$



Results

Sample Traffic Signs

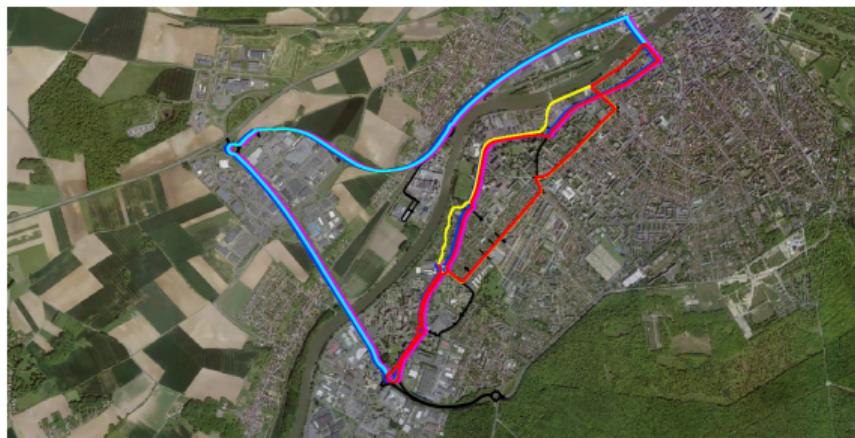


- 207 observed traffic signs
- 20 with added error



Results

Drives

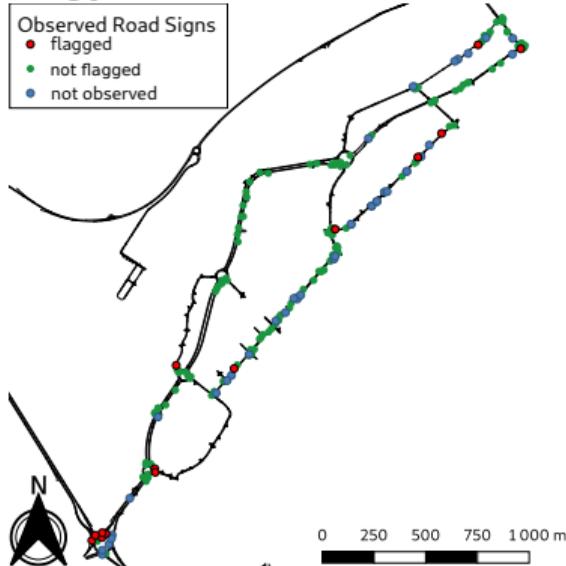




Results

Error Detection

First

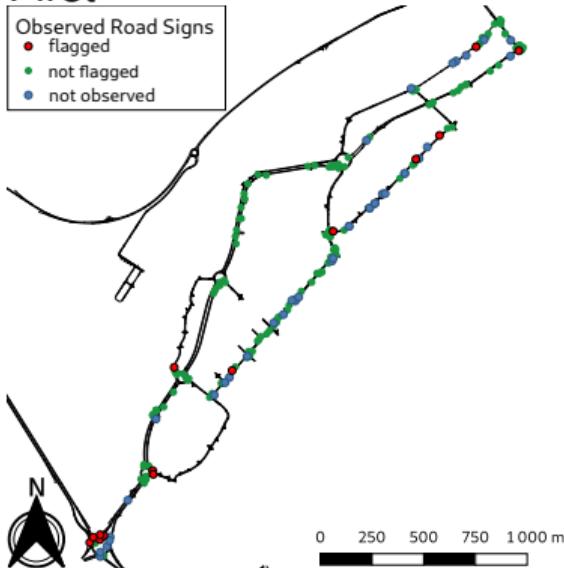




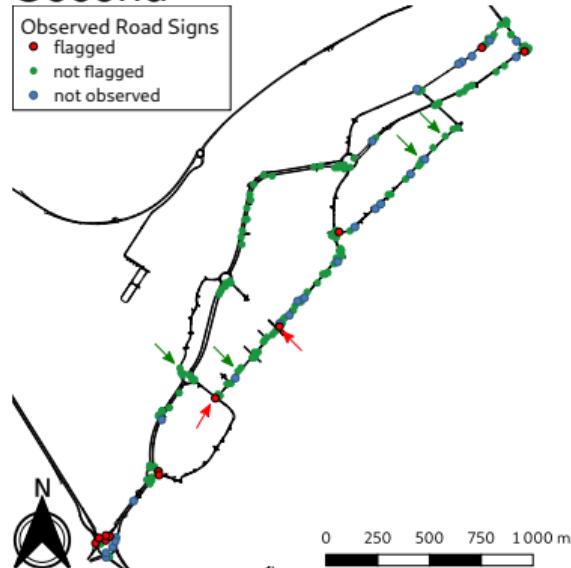
Results

Error Detection

First



Second

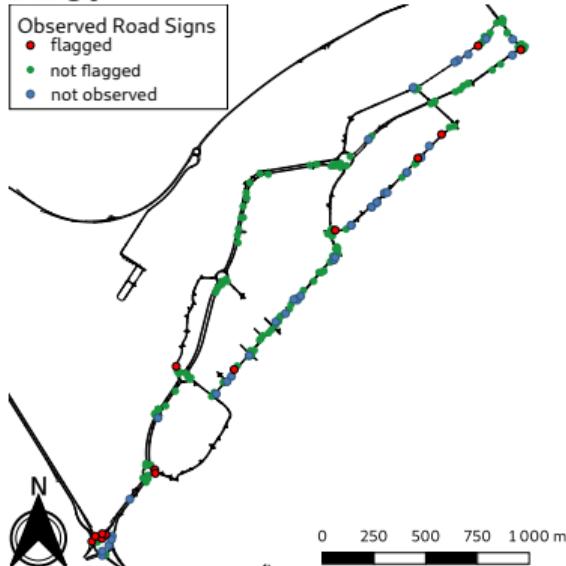




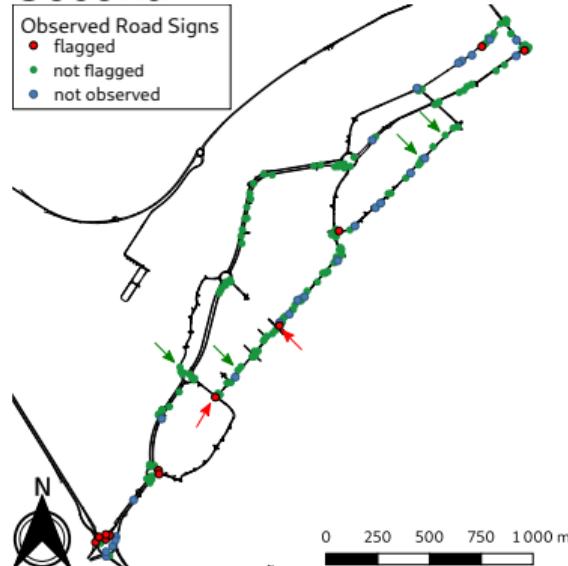
Results

Error Detection

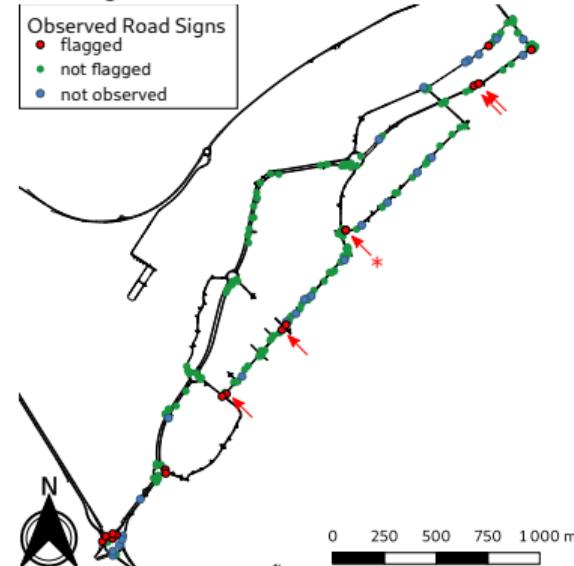
First



Second



Third

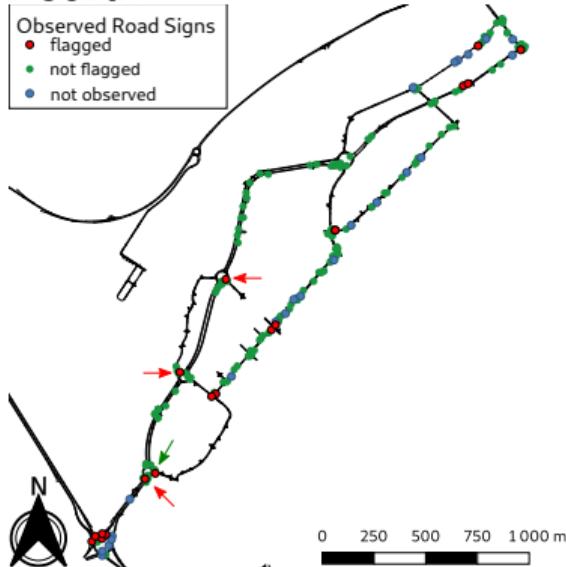




Results

Error Detection

Fourth

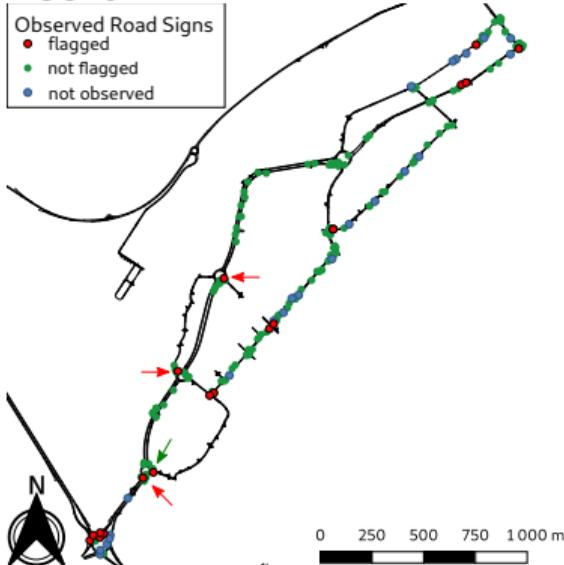




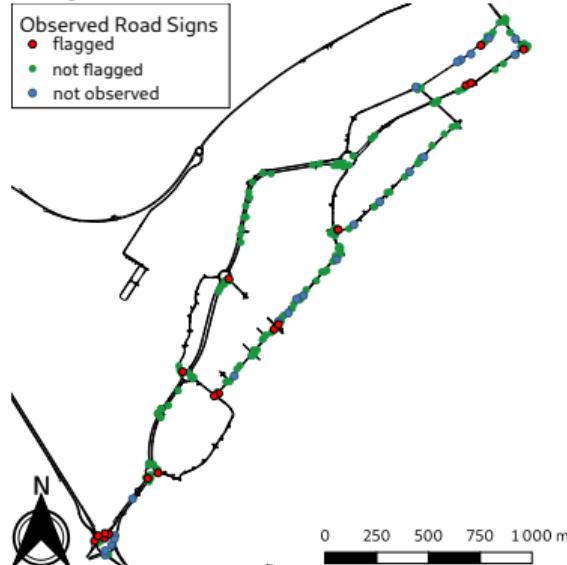
Results

Error Detection

Fourth



Fifth

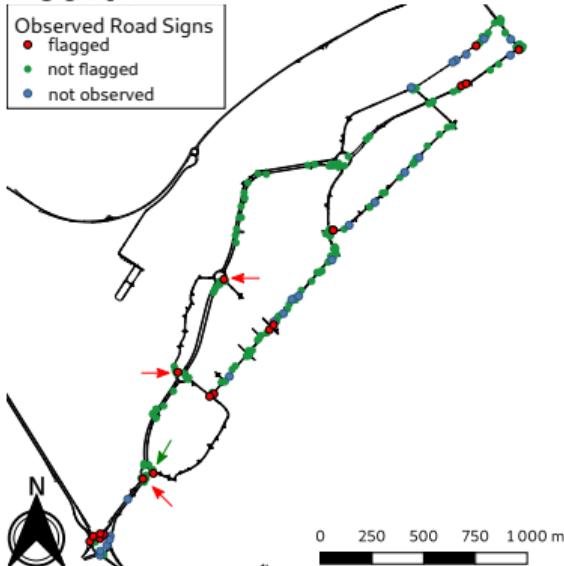




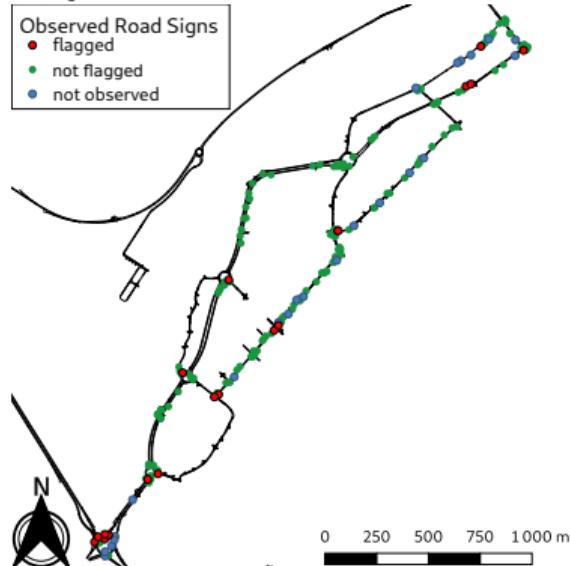
Results

Error Detection

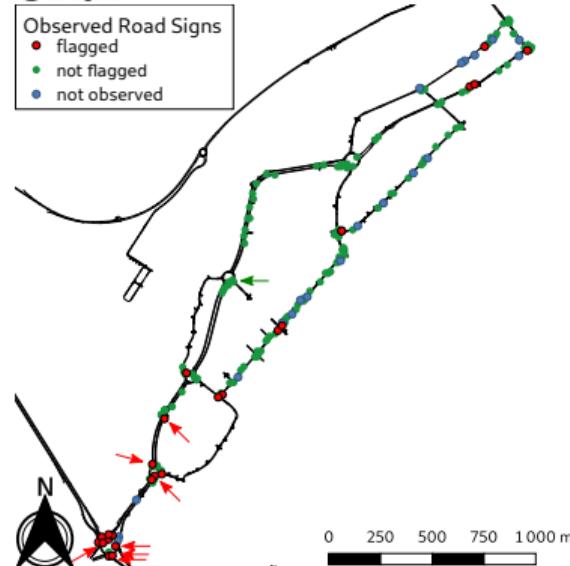
Fourth



Fifth



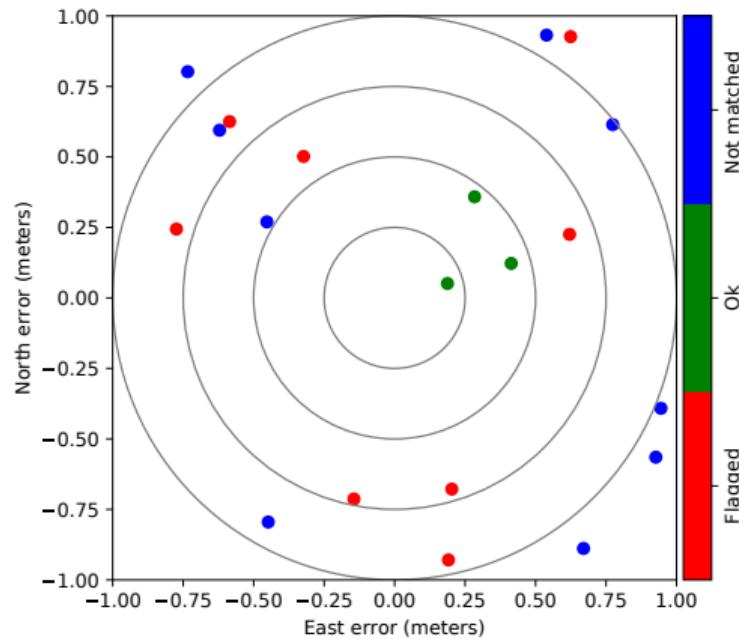
Sixth





Results

Error Detection





Perspectives

- Increase sensor redundancy
- Map correction
- Improve the fusion of multiple drives