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Mechtronic Lab

Integration of Landmark Detection and Low-cost Sensors for Vehicle Localization in Challenging Environments

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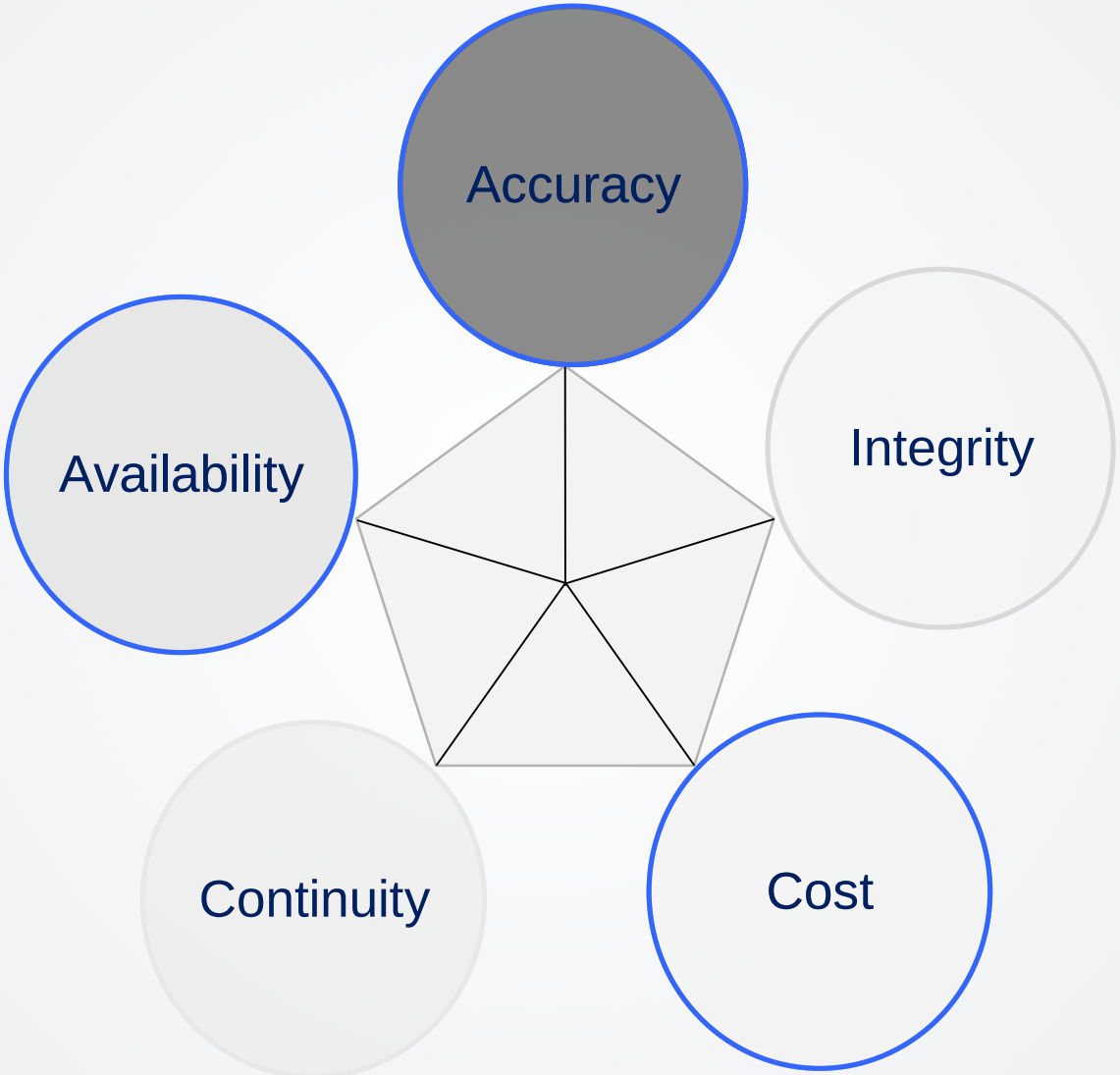
Presenter Introduction

Yu-Hsiang Wang received B. S. and M. S. degrees from National Cheng Kung University

I am a member of NCKU Car Team and focus on perception and localization technologies of self-driving.

We develop the autonomous vehicle and do proving ground validation in Taiwan Car Lab in Tainan, Taiwan.

Introduction



Introduction

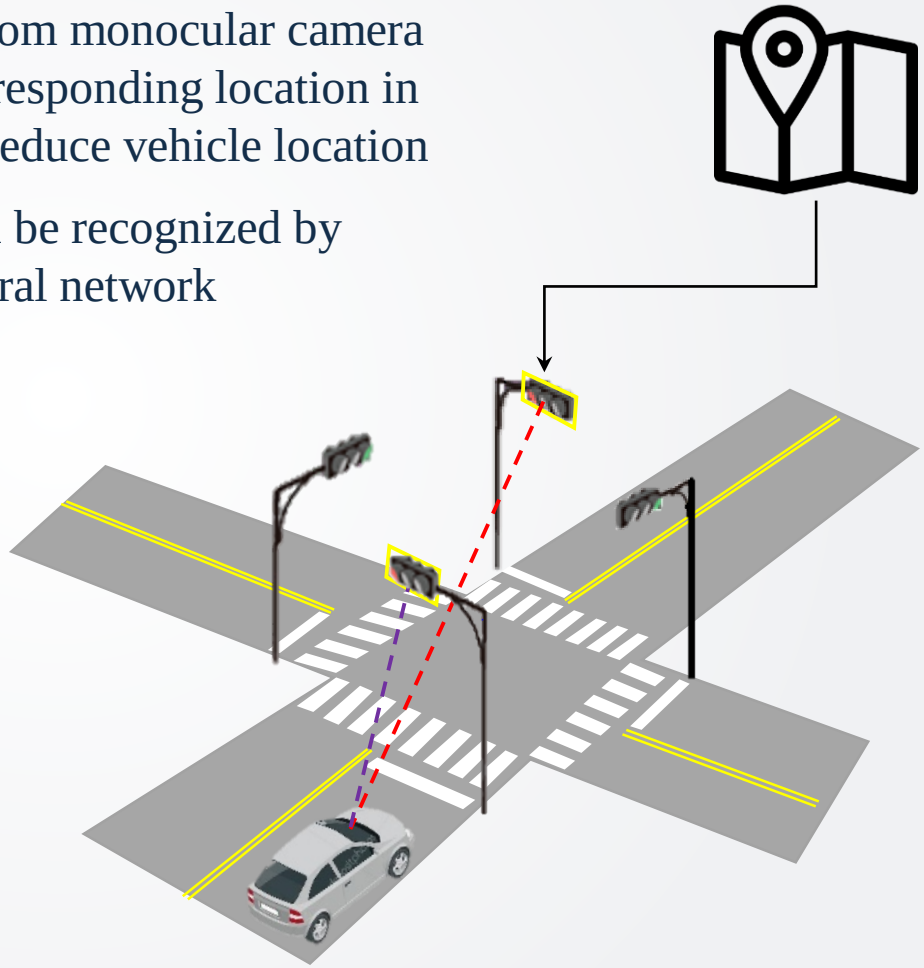
➢ Map matching based vehicle localization

- Integrate perception information from monocular camera and associate landmarks to the corresponding location in the High Definition (HD) map to deduce vehicle location
- Landmark features on the road can be recognized by using computer vision or deep neural network

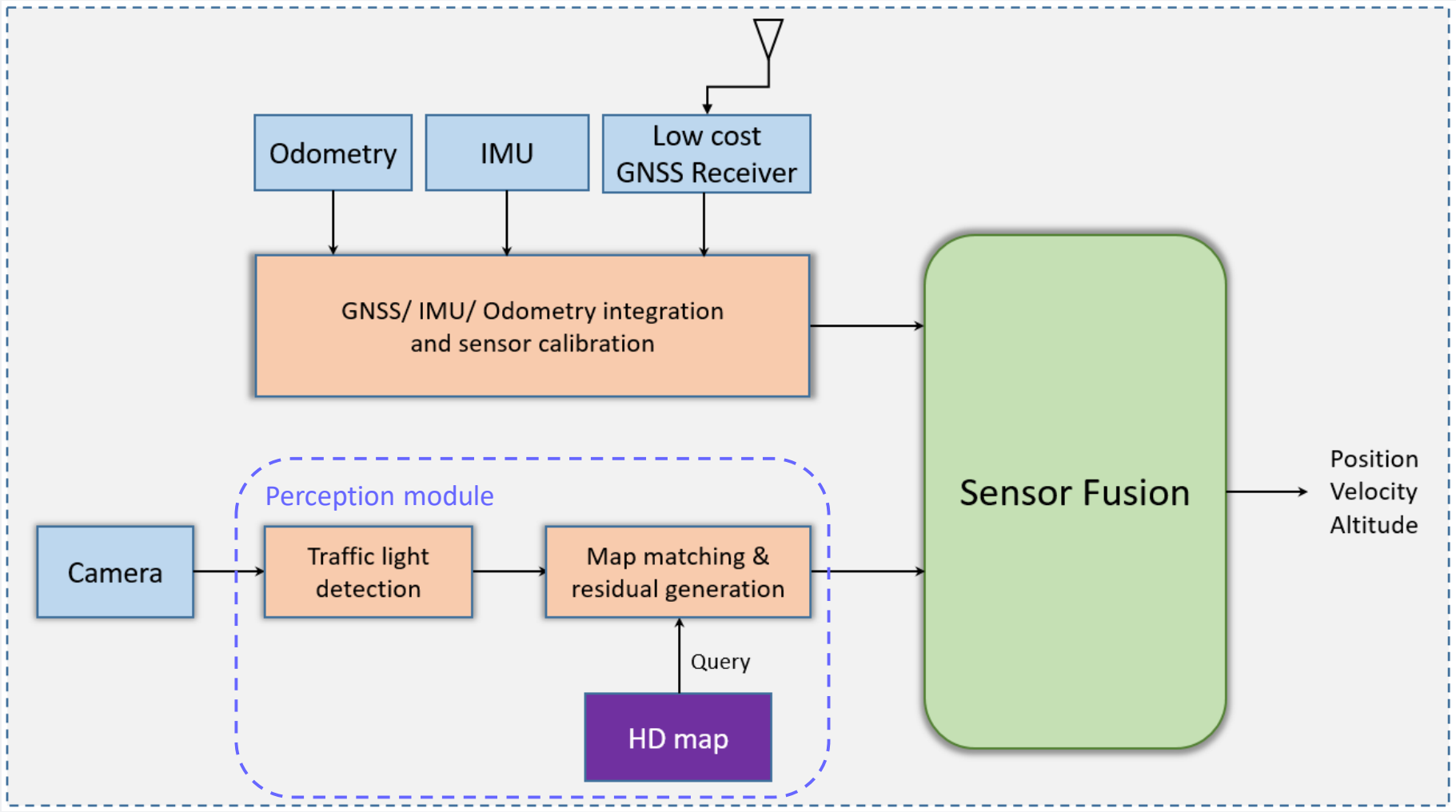
■Prominent vision features

■Long-term stability

■Appear in intersections



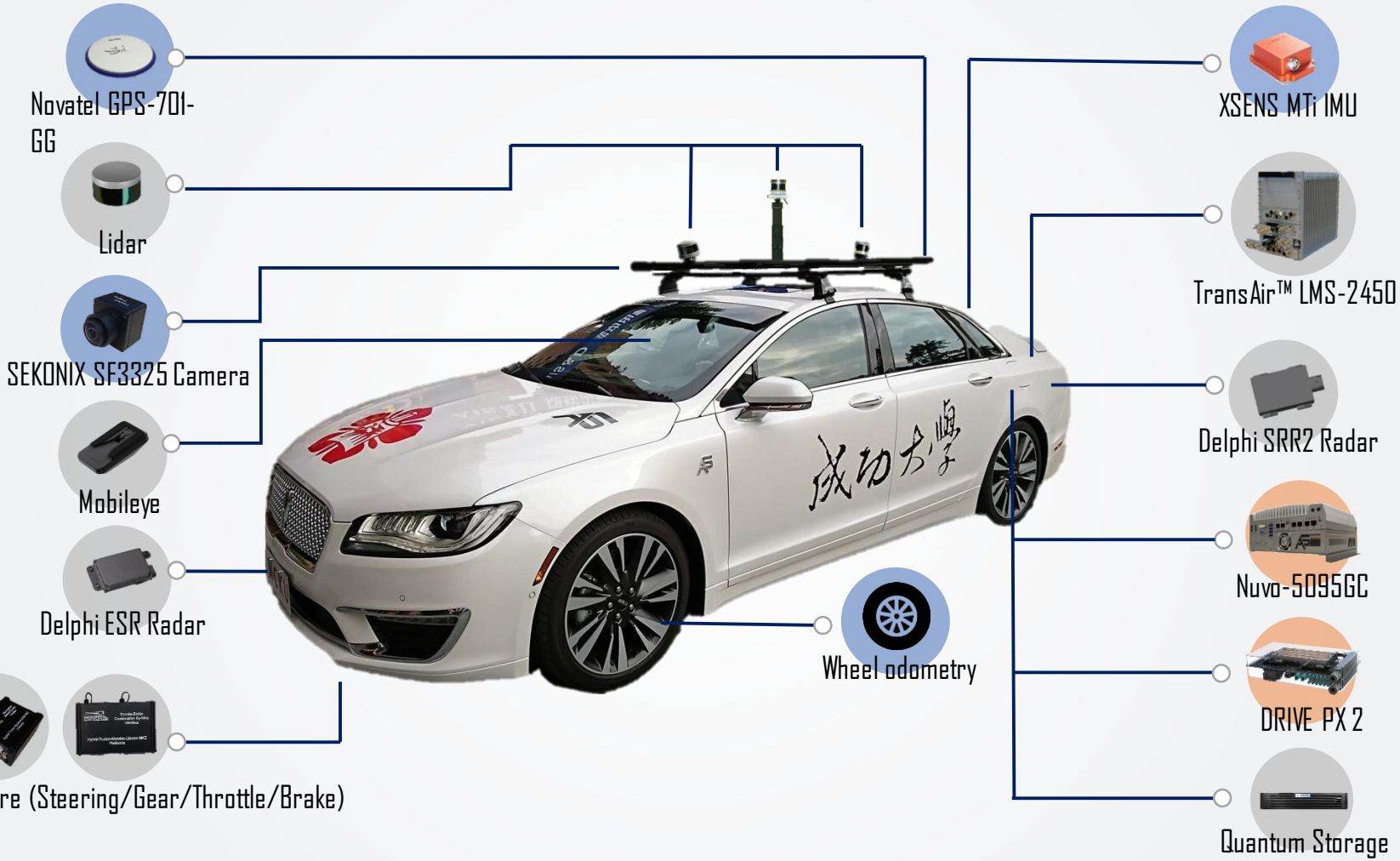
An Overview of our System



Contribution of this Work

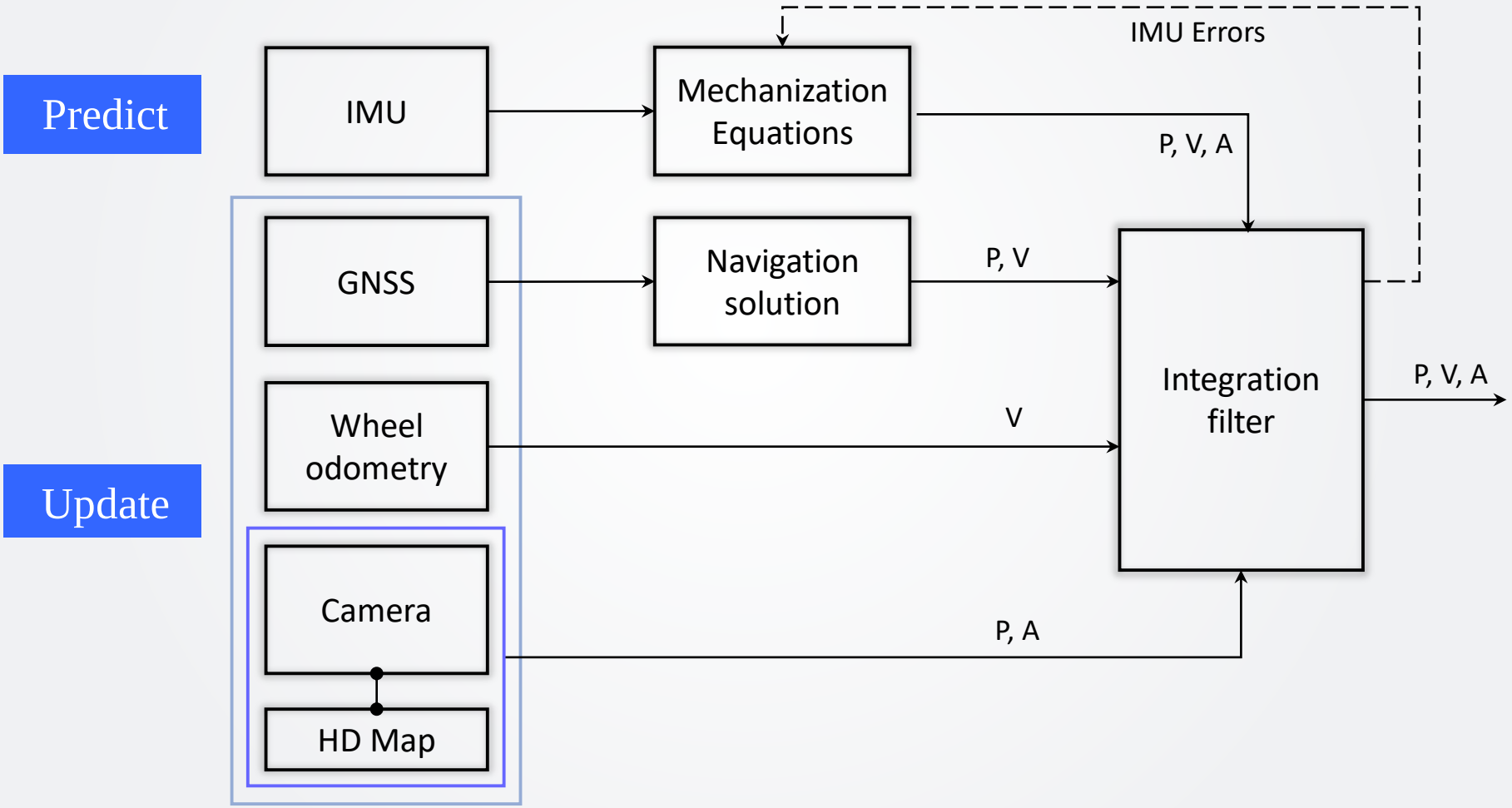
Develop a map-matching based scheme via combing image and HD map to improve the localization accuracy of a low-cost system as well as its availability.

Vehicle Platform



Vision-aided Loosely Coupled Integration

The integration filter is based on an extended Kalman filter



PnP - Bundle Adjustment

Minimize the re-projection error

$$\delta d_k^* = \arg\min_{\delta d_k} \frac{1}{2} \sum_{i=1}^{n} \left\| \tilde{d}_k^i - \hat{d}_k^i \right\|$$

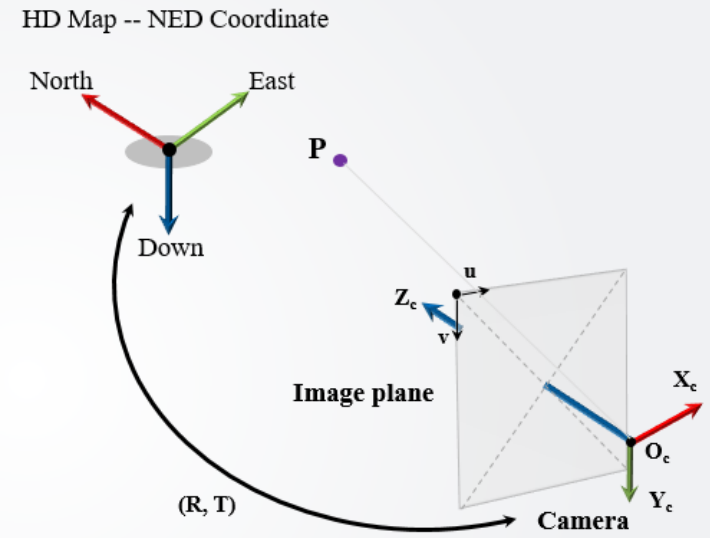
$$s \cdot \hat{d}_k^i = K \cdot [R \mid T]_n^c \cdot P^n = K \cdot e^{(\zeta^\wedge)} \cdot P^n$$

$$e_i = \tilde{d}_k^i - \hat{d}_k^i = \tilde{d}_k^i - \frac{1}{s} \cdot K \cdot \frac{1}{s} \cdot K \cdot [R \mid T]_n^c \cdot P^n$$

$$e_i(x + \Delta x) \approx e_i(x) + J(x) \cdot \Delta x$$

$$\frac{\partial e}{\partial \delta\zeta} = \lim_{\delta\zeta \to 0} \frac{e(\delta\zeta \oplus \zeta)}{\delta\zeta} = \frac{\partial e}{\partial P^c} \cdot \frac{\partial P^c}{\partial \delta\zeta}$$

Camera perturbation — Position in map



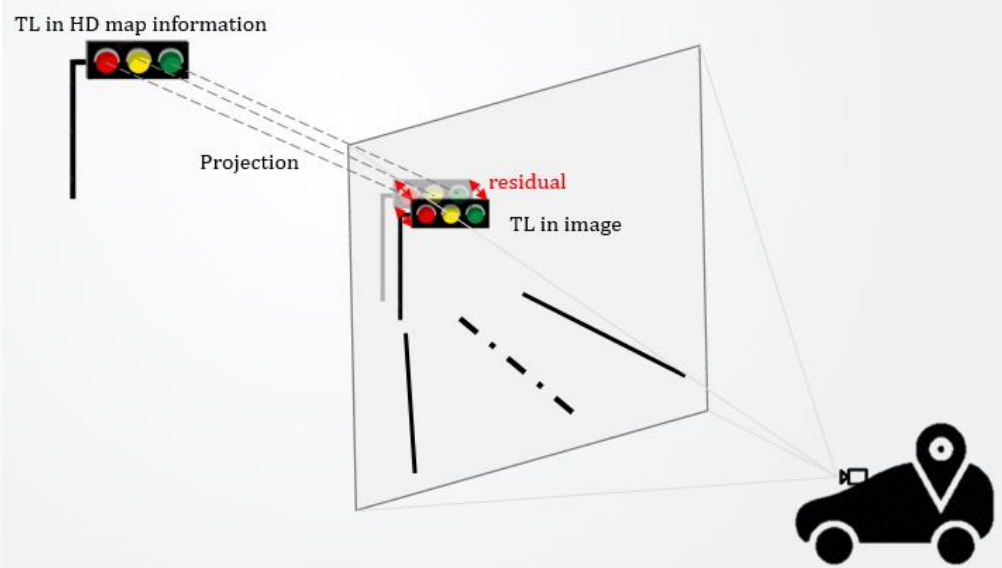
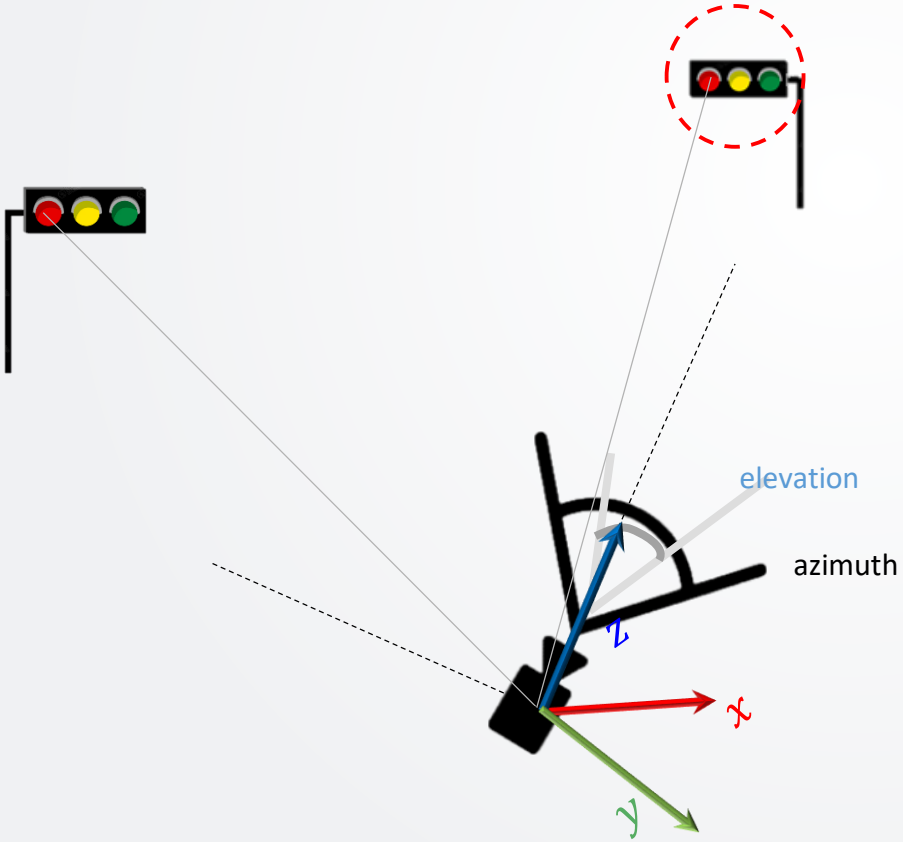
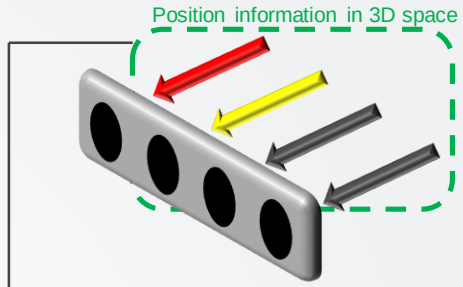


Image Processing - Re-projection

Re-projection HD Map information

$$s\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = K \cdot \left[\boldsymbol{R}_{3x3} \mid \boldsymbol{t}_{3x1} \right] \cdot \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \quad \text{with} \quad K = \begin{bmatrix} f_u & 0 & u_o \\ 0 & f_v & v_o \\ 0 & 0 & 1 \end{bmatrix}$$





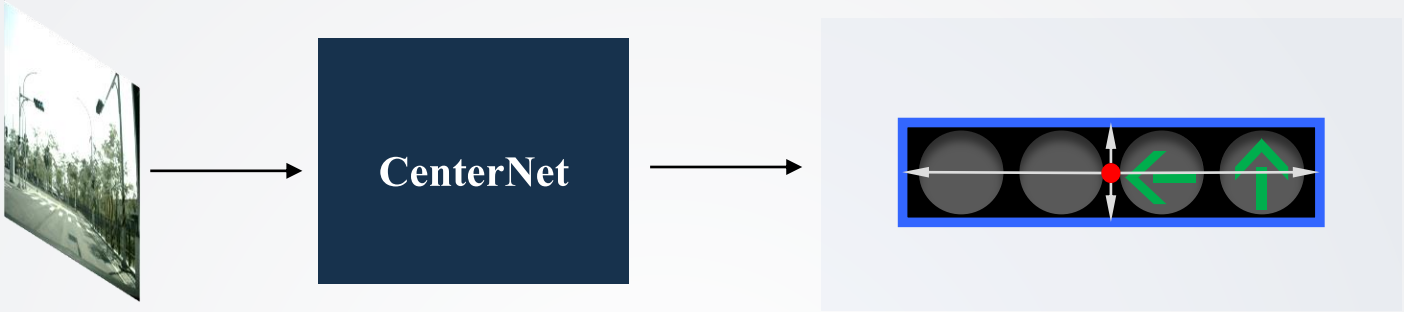
Signaldata

- ID
- Type: type of signal light
- VID: Vector ID
- PLID: Pole ID
- LinkID: reference to related Lane ID

Traffic light data structure in HD map

Image Processing - Detection

Deep neural network

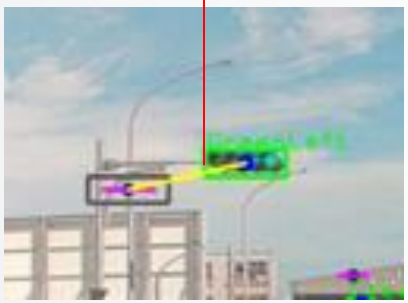


- This model is able to detect targets precisely
  - ✓ With fast inference time
  - ✓ With small computation
- The significant visual feature can be recognized even in the night time

Visual Measurement Model

Data association via a combination of Mahalanobis distance

$$y(\tilde{d}_t, \hat{d}_t) = \alpha \cdot \delta d_t^{iT} S_t^{-1} \delta d_t^i + (1-\alpha) \cdot \frac{\omega_d^{\,2}}{\sigma_d^{\,2}}$$



Measurement

$$\hat{d}_k = h(\hat{x}(k \mid k))$$

$$\delta d_k = \tilde{d}_k - \hat{d}_k = H_k \delta X_k + v_k$$

$$H_k = \left. \frac{\partial h}{\partial X} \right|_{x=\hat{x}(k|k)}$$

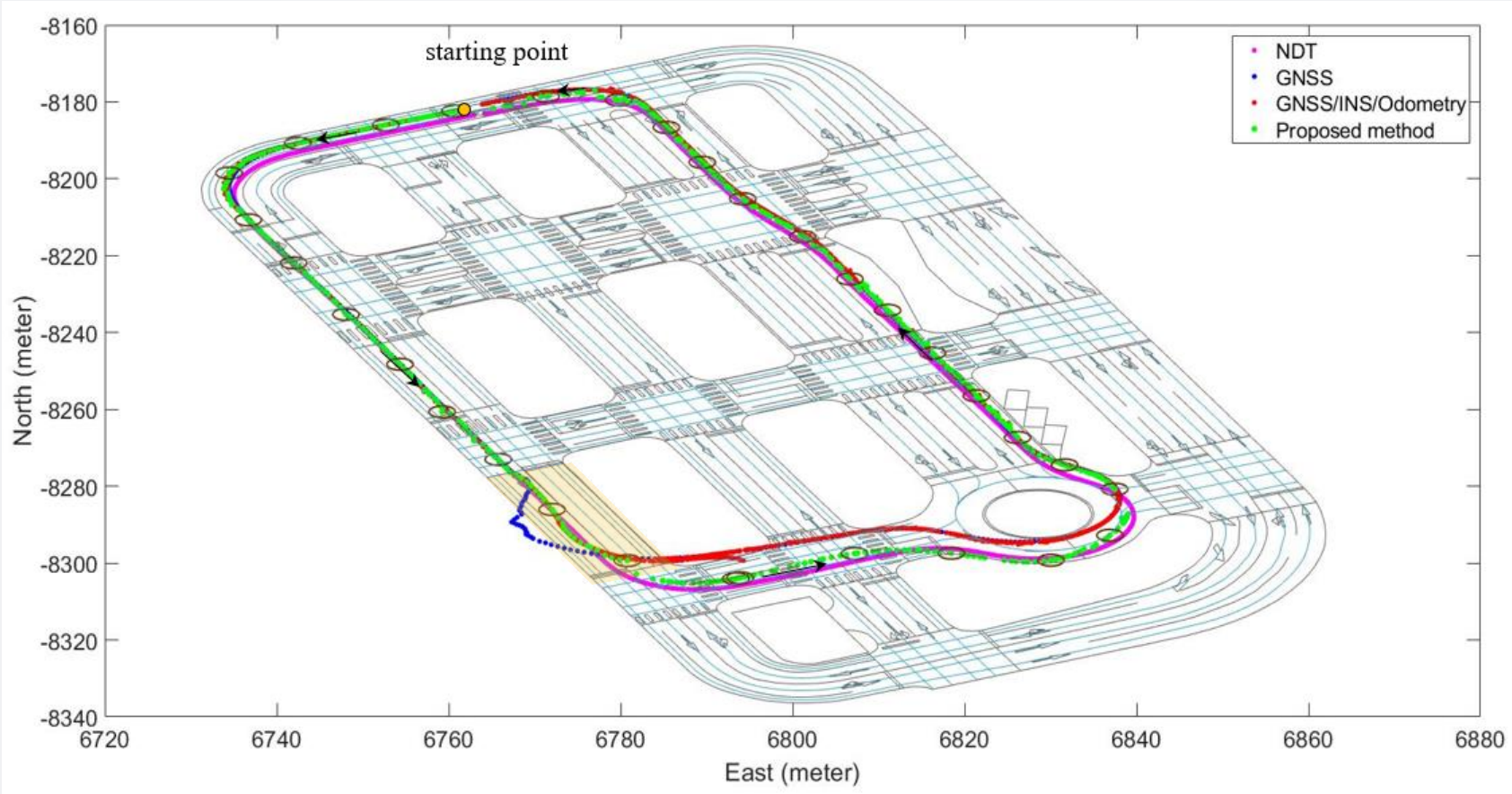
Bundle Adjustment

Measurement matrix

$$H_k = K_c DC \cdot \begin{bmatrix} -I_{3\times3} & 0_{3\times3} & [\hat{P}^c\times] & 0_{3\times6} \end{bmatrix}$$

$$K_c = \begin{bmatrix} fy & 0 \\ 0 & fx \end{bmatrix} \qquad D = \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix} \qquad C = (1/(\hat{z}_c)^2) \begin{bmatrix} \hat{z}_c & 0 & -\hat{x}_c \\ 0 & \hat{z}_c & -\hat{y}_c \end{bmatrix}$$

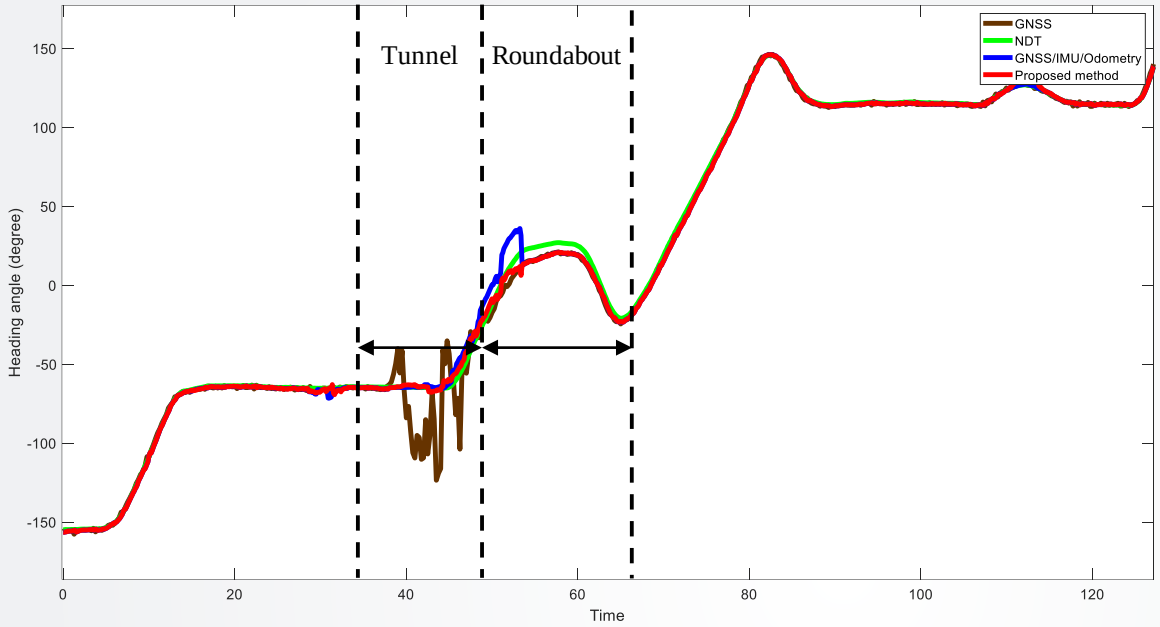
Experimental Results

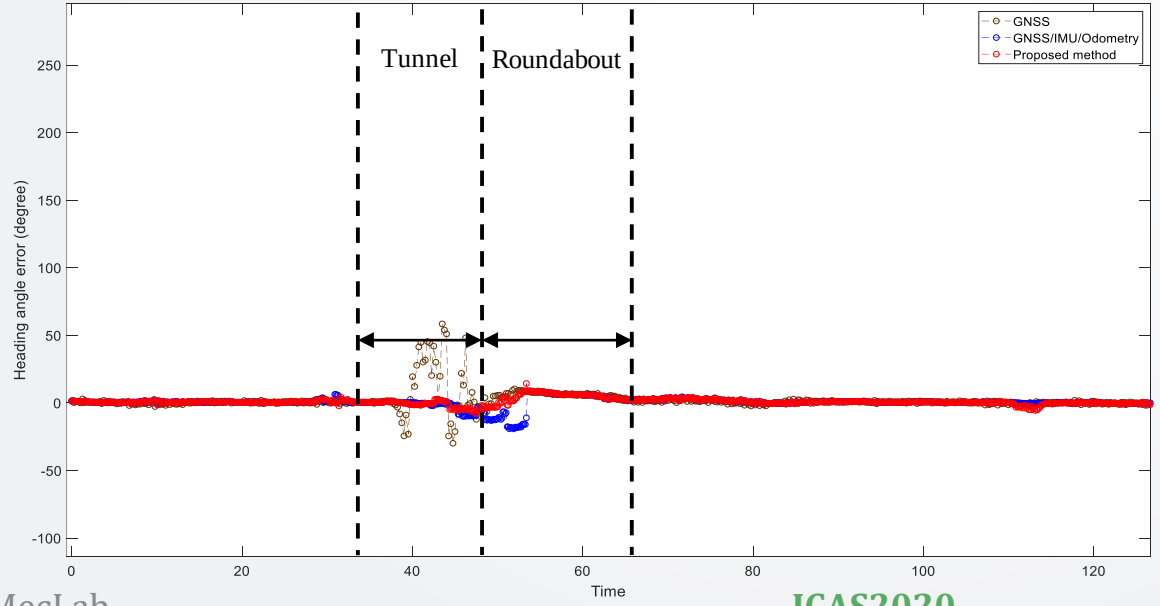


Localization errors compare to the reference

	GNSS	GNSS/IMU/Odometry	Proposed method
North error [m]	4.22	4.10	1.85
East error [m]	2.65	1.99	1.32

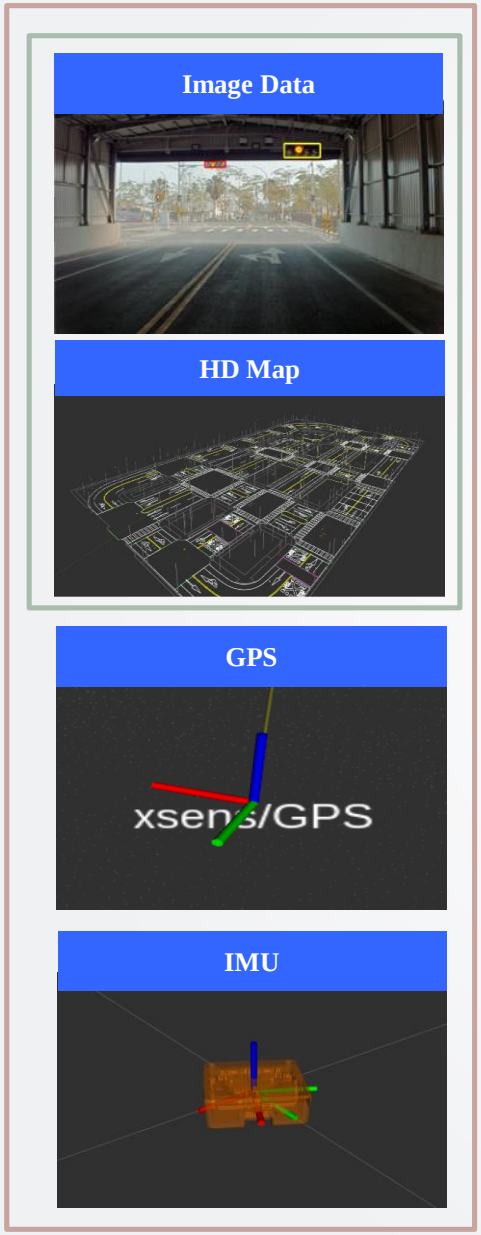
Experimental Results





- The heading angle error of the vehicle can be reduced below 5 degree

Conclusion



The map-matching based localization system is able to improve the localization accuracy and the availability of a conventional integration strategy

Future work

- There are more visual feature that should be exploited in an image such as lane line, traffic signs
- Online-calibrate camera parameters

Thanks for your attention.