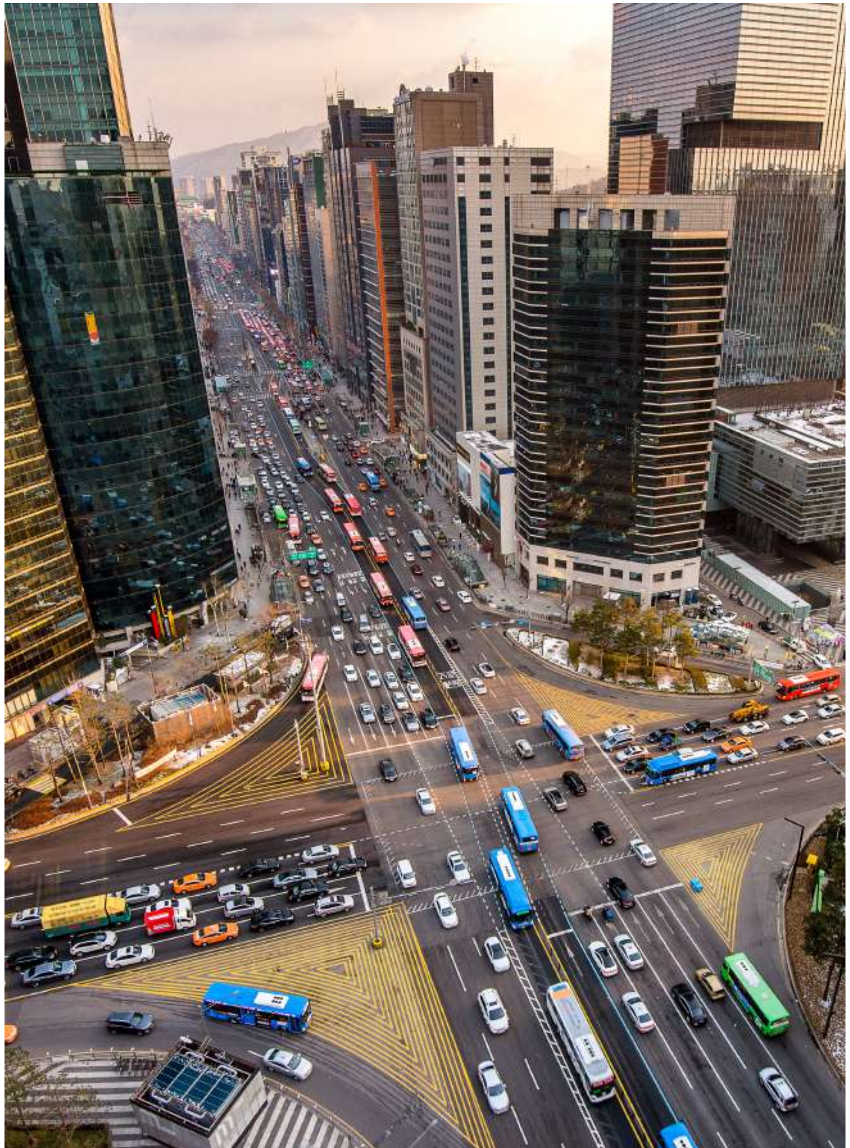
Uncertainty in DNN Models for multi – modal pose regression

MATTEO VAGHI

SUPERVISOR: DOMENICO G. SORRENTI



Autonomous Driving in Urban Areas

PROBLEMS

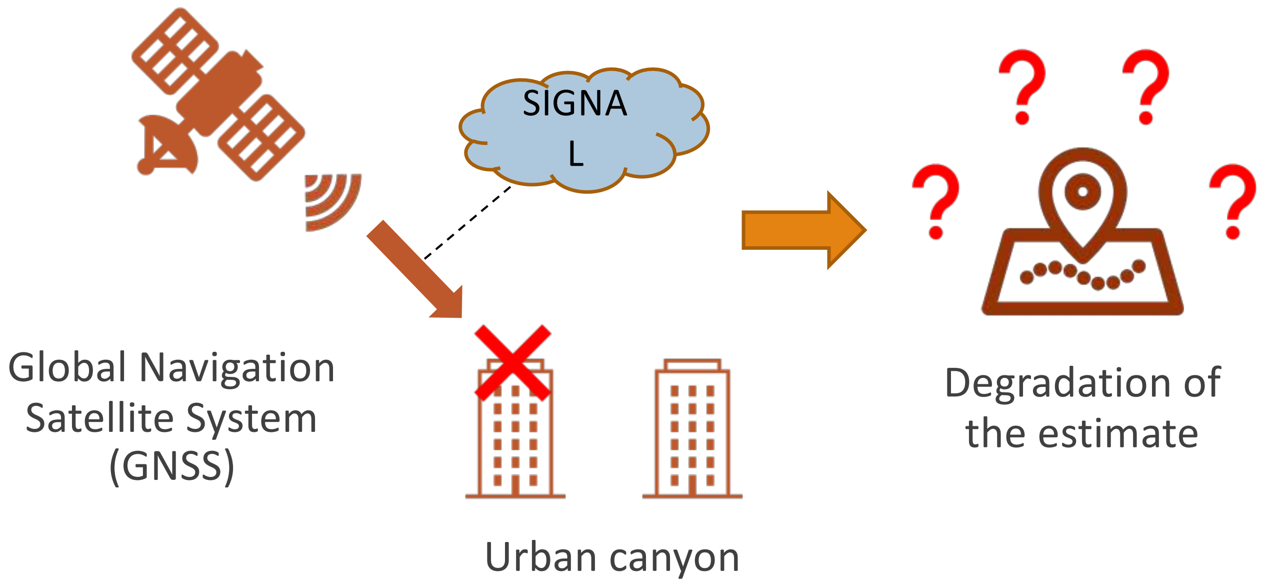
- Many road users (e.g., other vehicles and pedestrians)
- Complex structures (e.g., buildings and intersections)

OBSTACLES DETECTION **LOCALIZATION** **PATH PLANNING**

Localization

Definition:

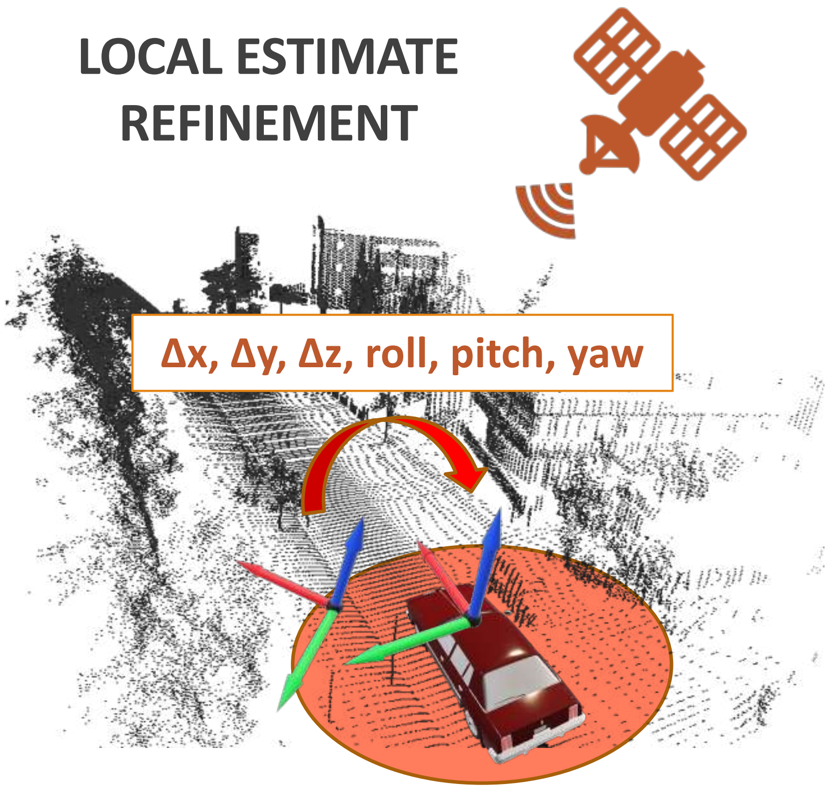
*Localization consists in the estimation of a **pose**, that is the position and orientation of a vehicle with respect to a known reference frame at a certain time.*

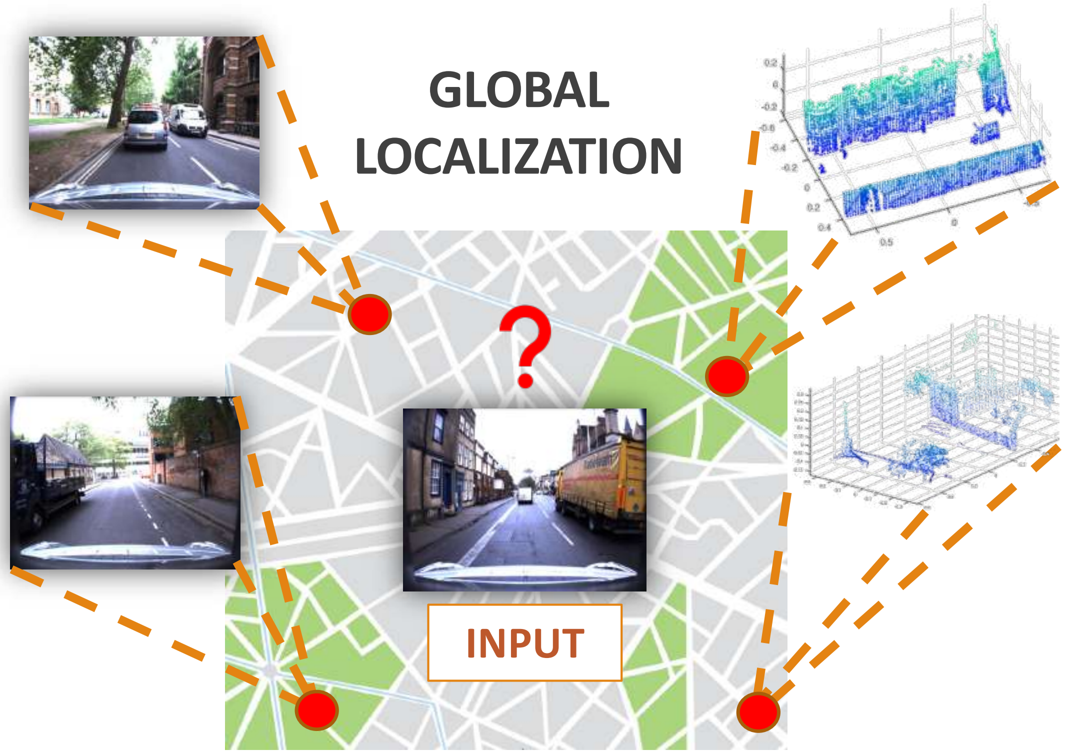


Localization through scene understanding:

- Cameras
- LiDARs (Light Detection and Ranging)
- Radars

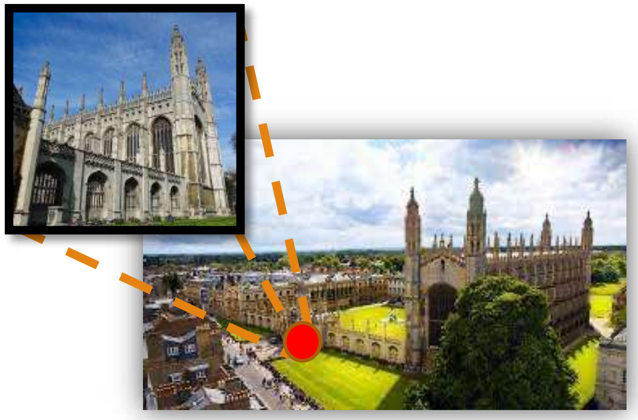
Localization: Local and Global





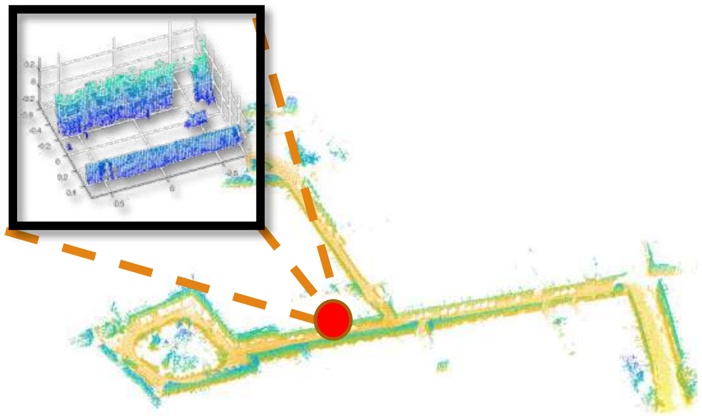
Existing approaches

CAMERA-BASED
- **Observer**: camera
- **Map**: set of images



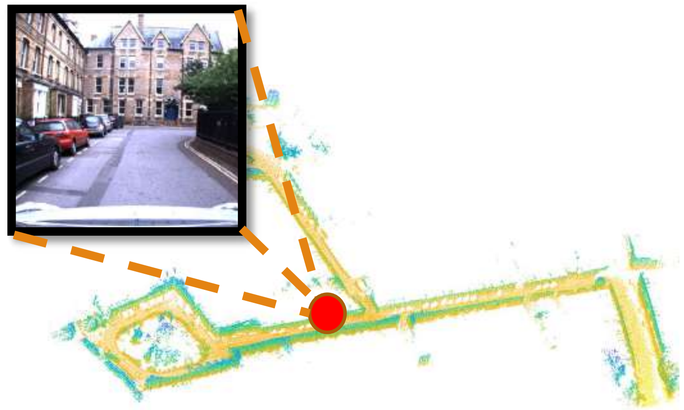
Shotton et al., 2013
Arandjelovic et al., 2016
Kendall et al., 2015
Radwan et al., 2018

PC-BASED
- **Observer**: point cloud
- **Map**: point cloud



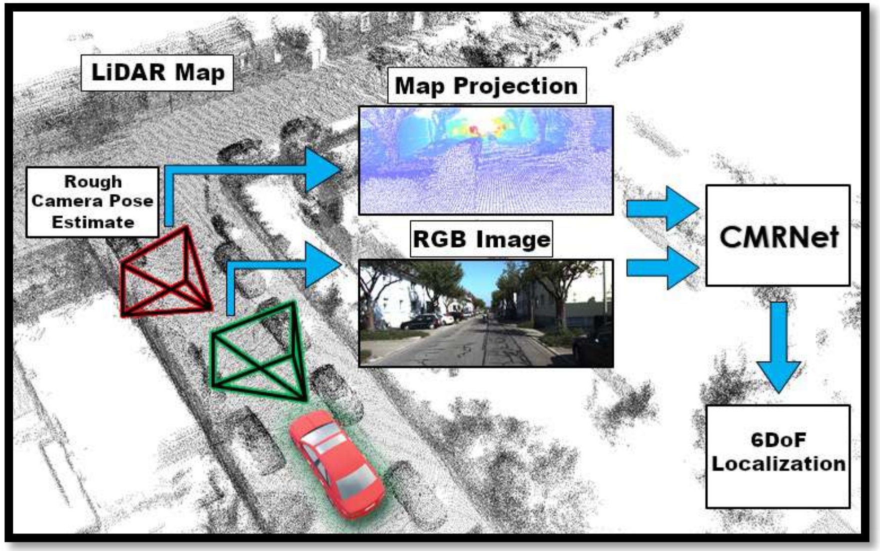
Zhang et al., 1994
Cattaneo, Vaghi et al. 2022
Aoki et al., 2018
Yew et al., 2020

CAMERA-TO-PC
- **Observer**: camera
- **Map**: point cloud



Caselitz et al., 2016
Feng et al., 2019
Cattaneo et al., 2019
Cattaneo et al., 2020

Case Study: CMRNet

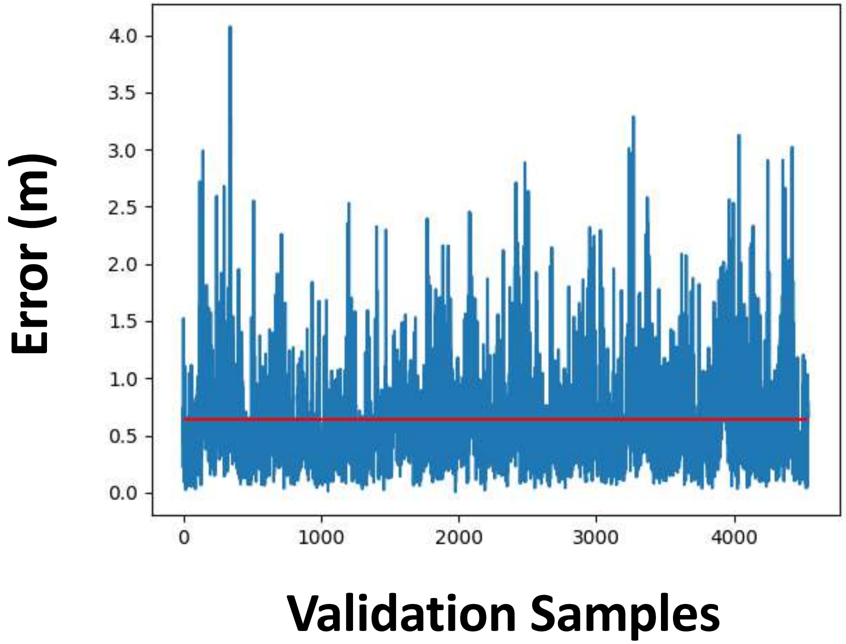


Cattaneo, Vaghi et al., 2019

- Rely on geometry and visual information
- Only cameras on-board vehicles
- Outstanding results on local localization task

Initial error range: **[-2m, 2m]** and**[-10°; +10°]**
Median translation error: **0.46 m**
Median rotation error: **0.97°**

CMRNet reliability



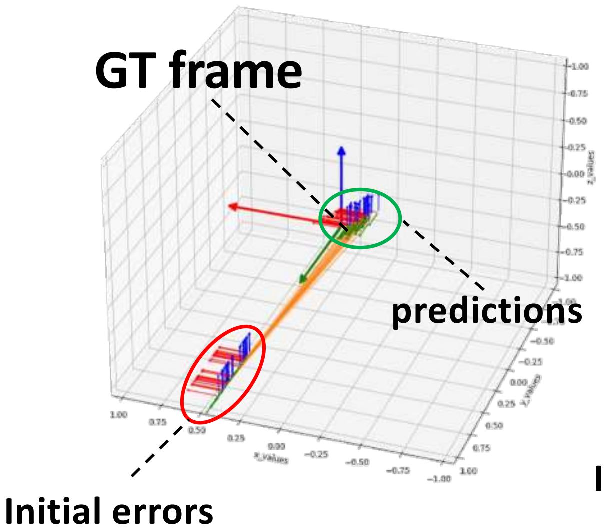
Issues:

- Presence of large errors
- Approach not suitable for critical scenarios

Analysis of CMRNet accuracy in different scenarios (1)

(a)

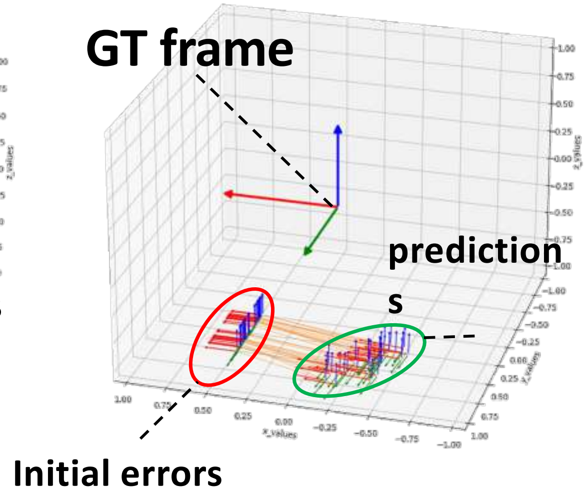
(b)



(a)

AVG Accuracy:

0.48 m 1.7°



(b)

AVG Accuracy:

0.98 m 1.2°

Uncertainty Estimation

Uncertainty:

- Situations in presence of imperfect or unknown information
- **Epistemic:** when estimated wrt the model output
  - The aim is to represent a posterior probability distribution $\mathrm{p}(\boldsymbol{\theta}|\boldsymbol{D})$

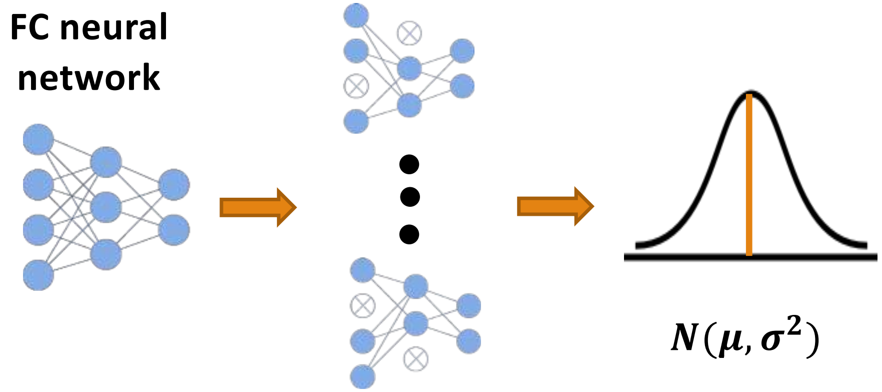
Few approaches for camera localization:

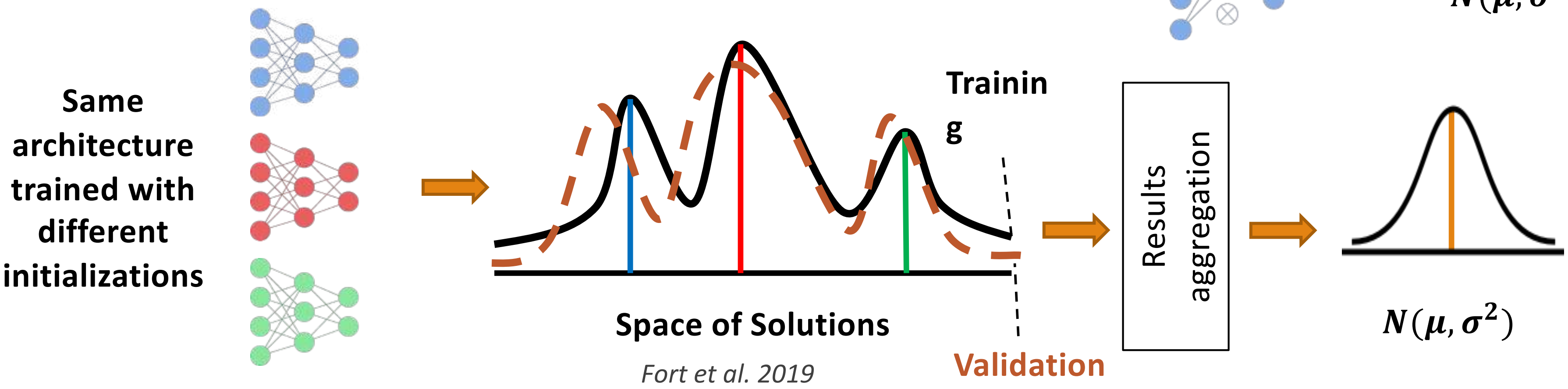
- Camera-only (*Kendall et al. 2017*)
- Lack of comparison between existing methods

Approaches for uncertainty estimation in a regression task

In deep learning there are three different approaches:

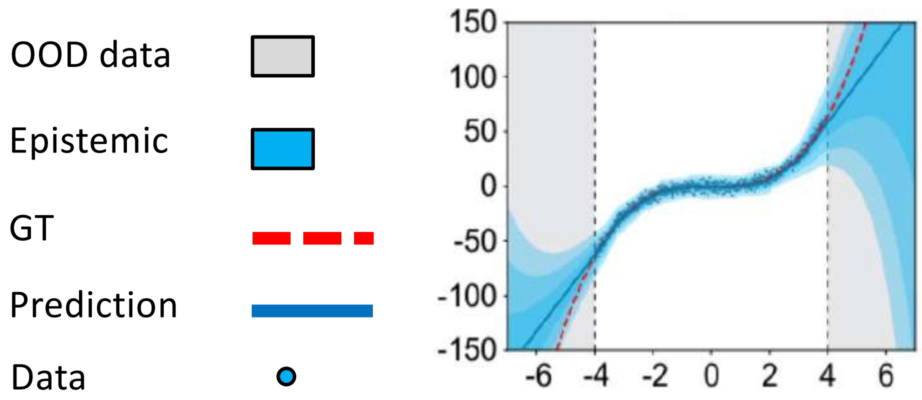
- Monte Carlo dropout (Gal et al. 2016)
- Deep Ensemble (Lakshminarayanan et al. 2017)
- Deep Evidential regression (Amini et al. 2020)





Deep Evidential Regression

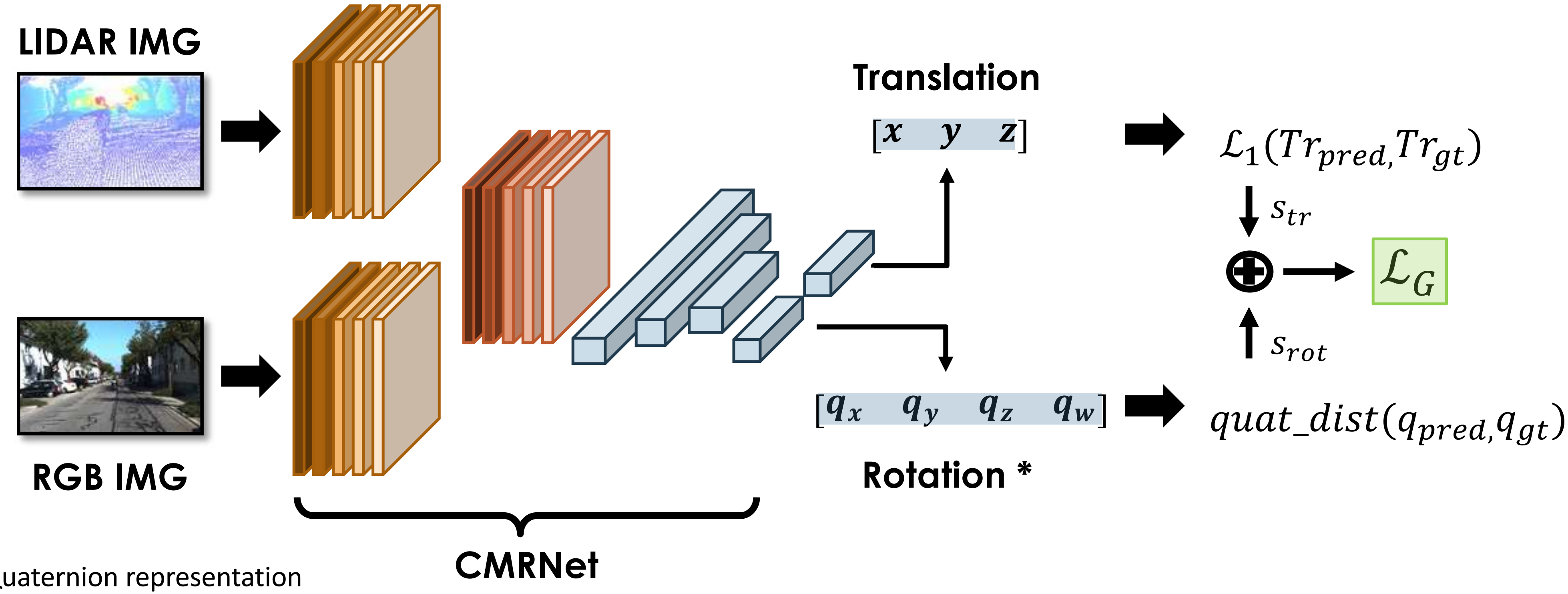
- Model learns to predict parameters of a **Normal Inverse Gamma** distribution:
  $$\boldsymbol{m} = (\boldsymbol{\gamma}, \boldsymbol{\nu}, \boldsymbol{\alpha}, \boldsymbol{\beta})$$
- Direct uncertainty estimate
- Regression of a value **x**:



Prediction: $\mu_x = \boldsymbol{\gamma}$

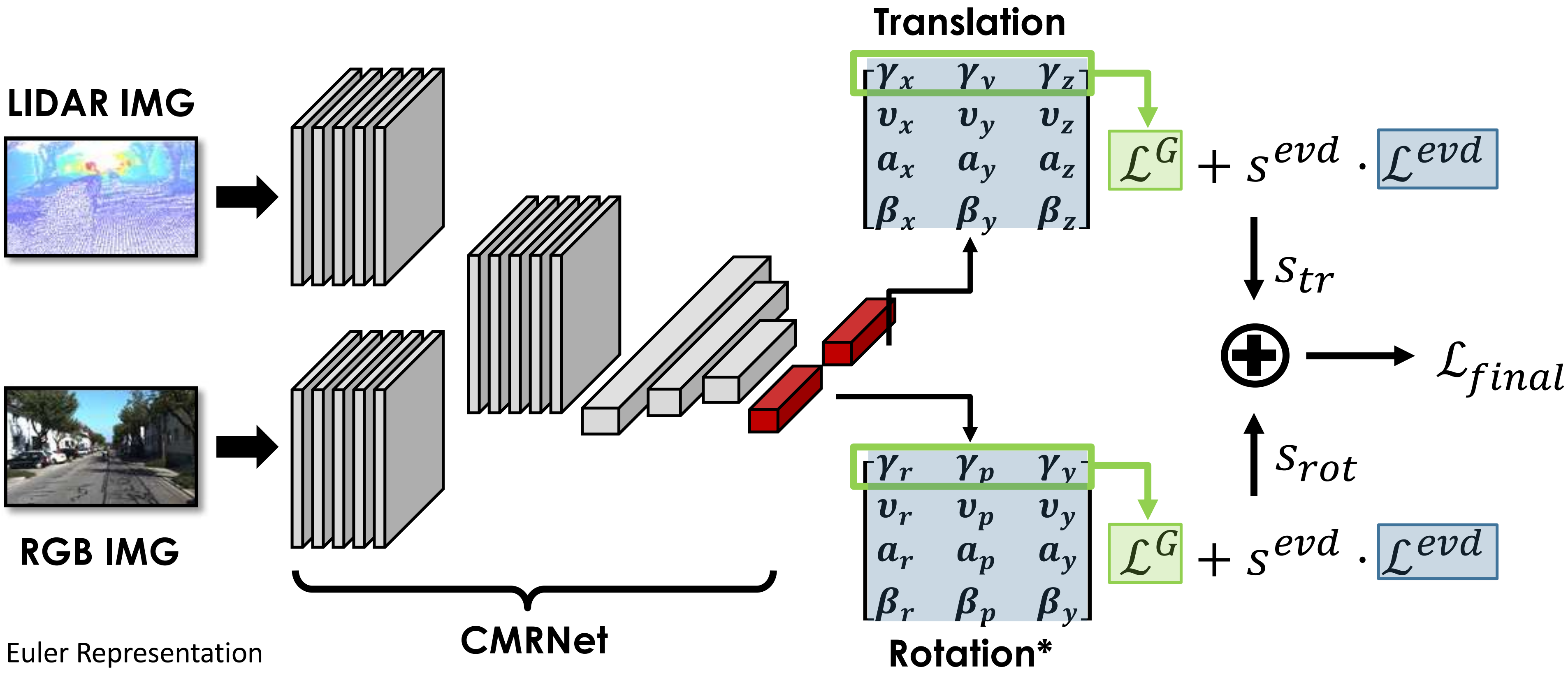
Epistemic: $\sigma_x^2 = \dfrac{\boldsymbol{\beta}}{\boldsymbol{v}(\boldsymbol{\alpha}-\mathbf{1})}$

UA-CMRNet with Deep Evidential Regression (1)



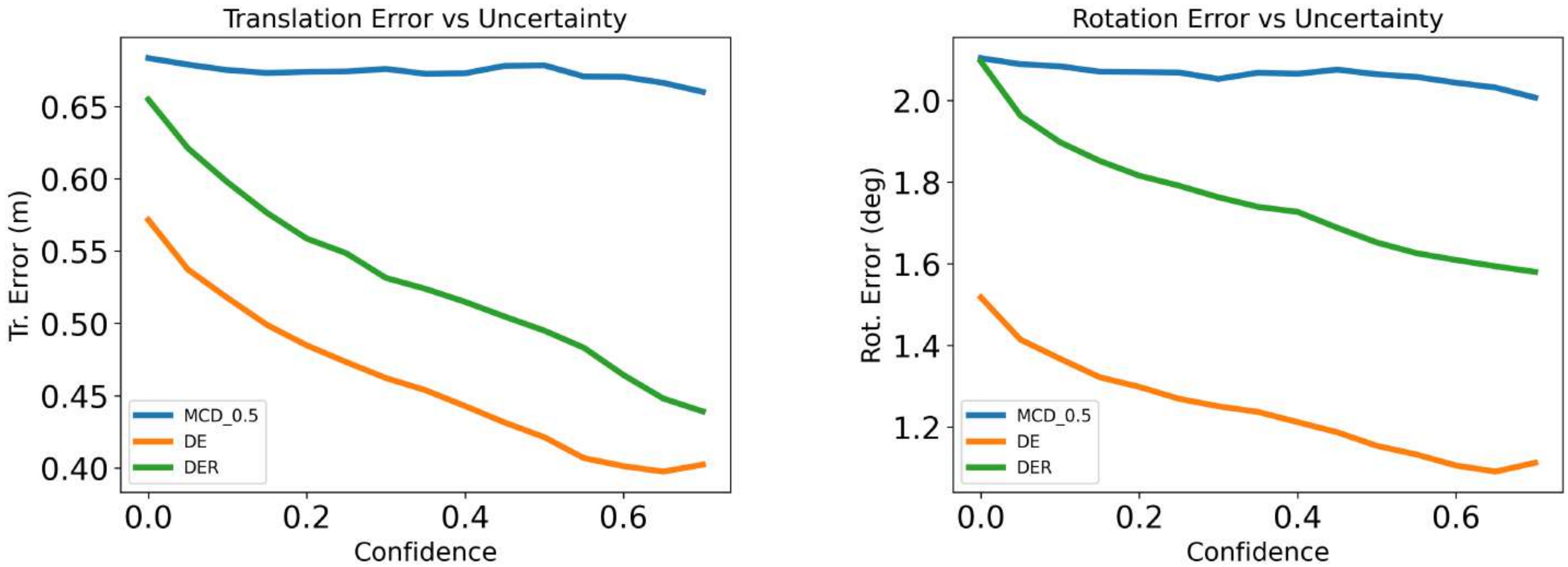
* Quaternion representation

UA-CMRnet with Deep Evidential Regression (2)

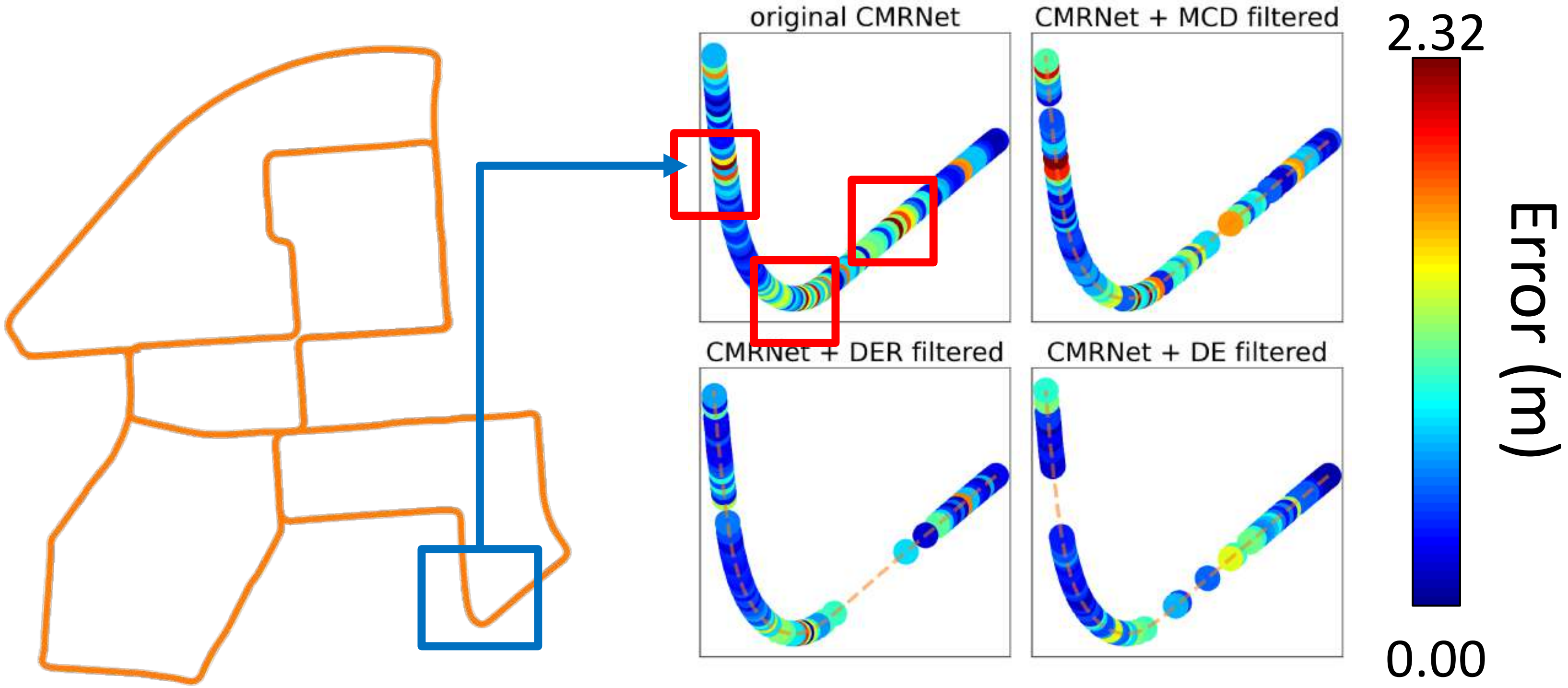


* Euler Representation

UA-CMRNet results: detecting localization failures (1)



UA-CMRNet results: detecting localization failures (2)



run 00 – KITTI dataset

Localization Accuracy

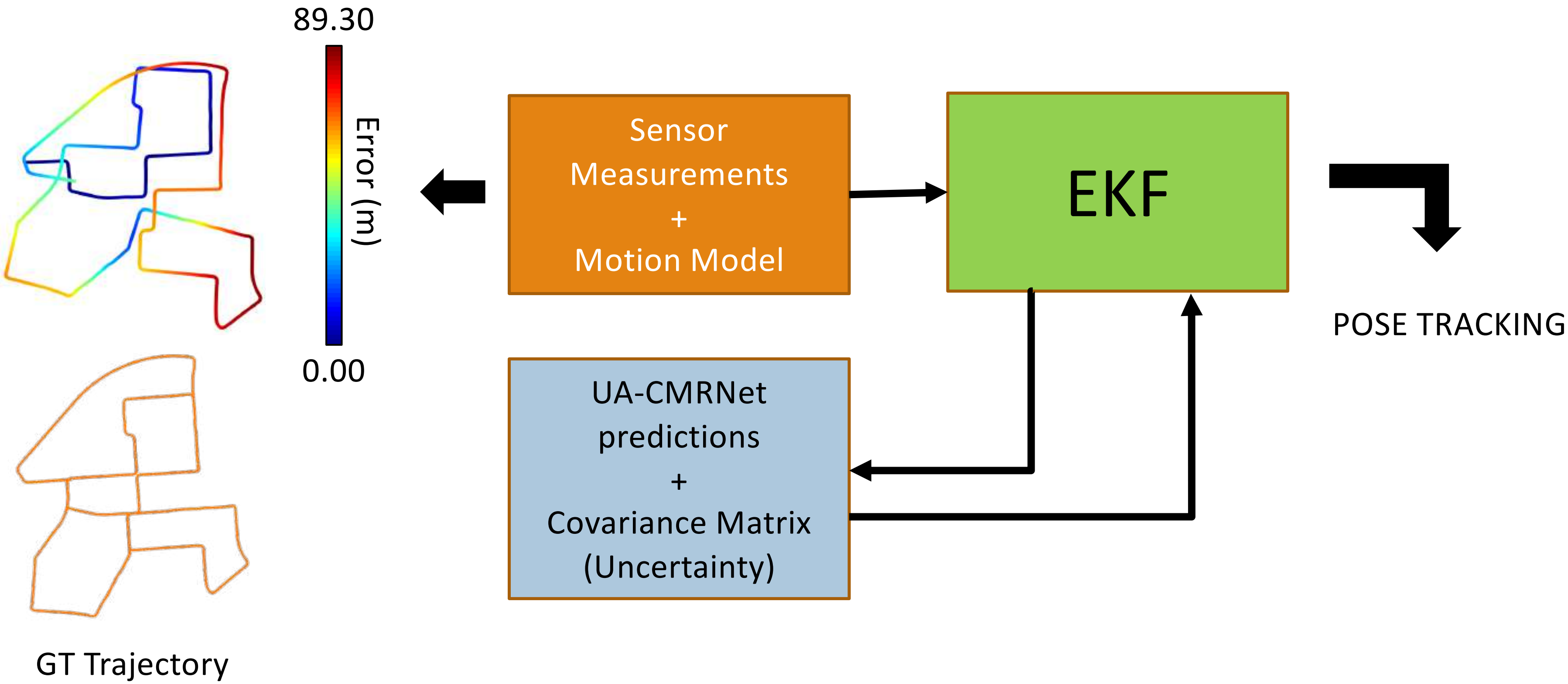
- CMRNet + DE achieves best localization results
- Reduction of std in the error distribution and good uncertainty estimates
- CMRNet + DER advantage of directly estimating uncertainty with a single prediction

Method	Translation Error (m)		Rotation Error (deg)	
	median	mean/std	median	mean/std
Initial Error	1.88	1.82 ± 0.56	9.8	9.6 ± 2.8
CMRNet (no iter)	0.51	0.64 ± 0.46	1.3	1.6 ± 1.2
CMRNet + MCD	0.57	0.68 ± 0.44	1.8	2.1 ± 1.3
CMRNet + DE	**0.47**	**0.57 ± 0.39**	**1.2**	**1.5 ± 1.1**
CMRNet + DER	0.54	0.65 ± 0.46	1.8	2.1 ± 1.4

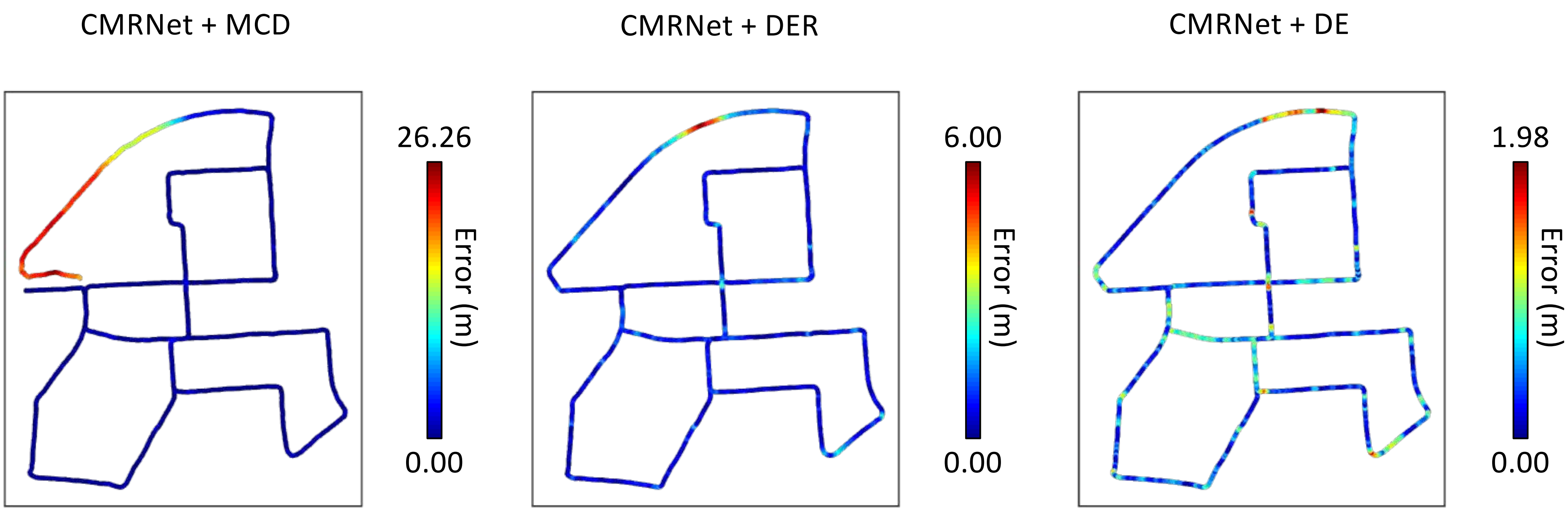
Method	Translation Error (m)		Rotation Error (deg)		Filtered Pred.
	median	mean/std	median	mean/std	
MCD	0.57	0.67 ± 0.44	1.8	2.1 ± 1.3	27.2%
DE	0.42	0.50 ± 0.32	1.1	1.3 ± 0.8	24.7%
DER	0.49	0.58 ± 0.38	1.6	1.9 ± 1.1	22.0%

M. Vaghi et al., **A comparison of uncertainty estimation approaches for DNN-based camera localization**, submitted to the Internation Conference of Robotics and Automation, London, 2023

UA-CMRNet: application within an EKF



UA-CMRNet: application within an EKF (2)



Thank you for your attention!