Research Center Space
Universität der Bundeswehr München

Session C2: Multisensor Integrated System Technologies

3D LiDAR-IMU Integration for State Estimation and Verification Using a GNSS/INS/LiDAR Simulation Chain

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Motivation and Paper/Presentation Contents

Complete control of the environment and vehicle dynamics

Changing sensors configuration

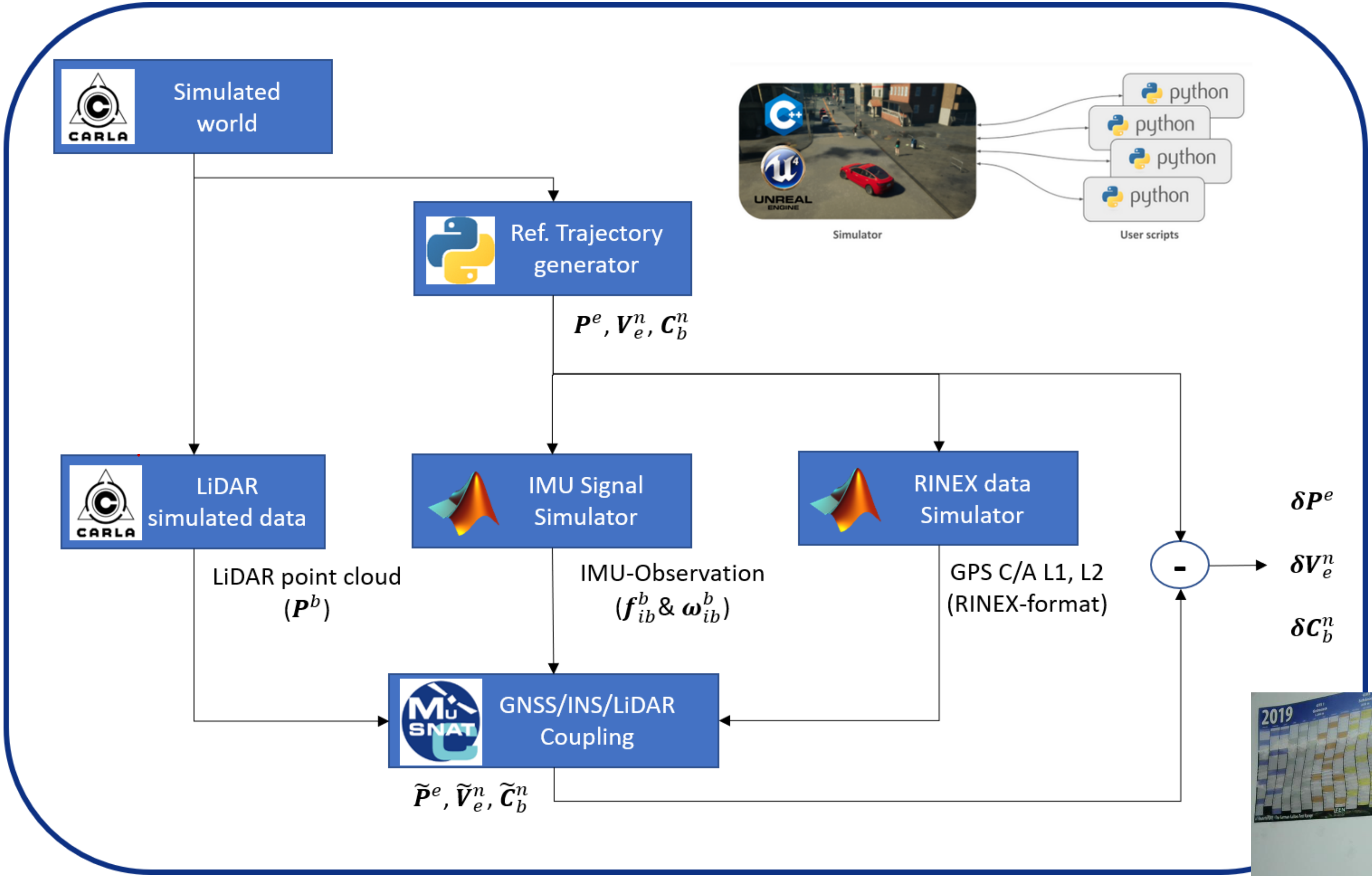
Repeatability of tests scenarios

Contents

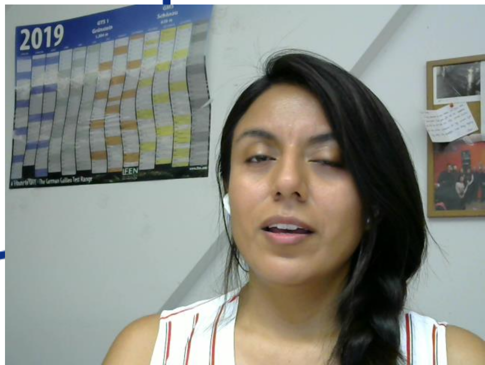
- Extended SIMSS tool overview
- Synthetic LiDAR data and trajectory generation
- LiDAR processing
- Trajectory-based IMU simulator
- INS/LiDAR EKF
- Future developments

Extended SIMSS tool

Modules added to the SIMSS tool & new data flow



Extended Satellite and Inertial Measurement Simulation System (Extended-SIMSS)

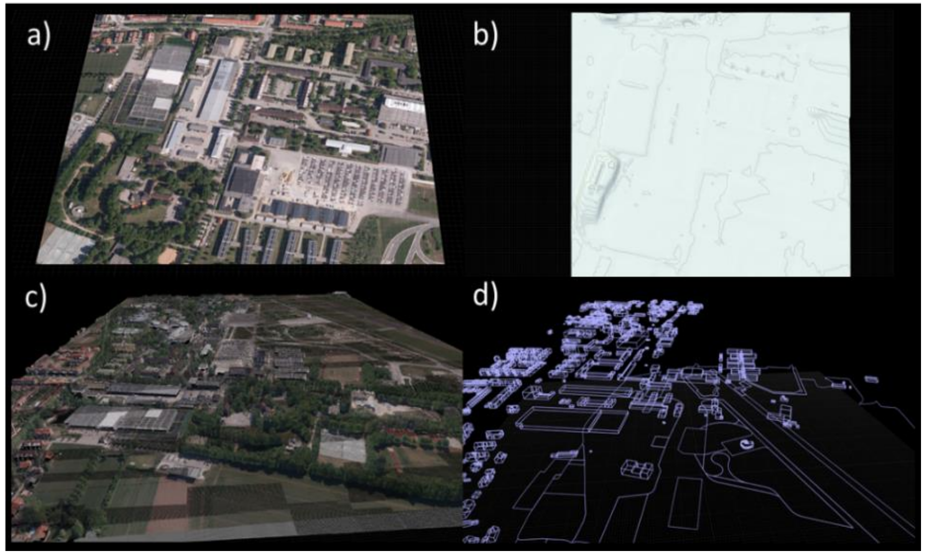


Synthetic LiDAR data and trajectory generation

How CARLA is used and configured in order to get synchronized data and the workflow in order to get a customizable trajectory.

Map generation

- Prebuilt maps offered in CARLA: cities, towns, highways, etc…
- Generate a custom maps:
  - Different scenery
  - Control of the environment (buildings, trees, etc)
  - Road definition
  - Specific configuration for the application or test



GIS Data

Aerial Imagery, elevation map, point cloud data, vector data

VECTORZERO Roadrunner

Preprocessing

Geographic transformation to GIS data layers

→

3D scene construction

Buildings
Roads
Markings
Artifacts: traffic signs, trees, poles, etc.

→

Map validation

Roads logic
Assets texture

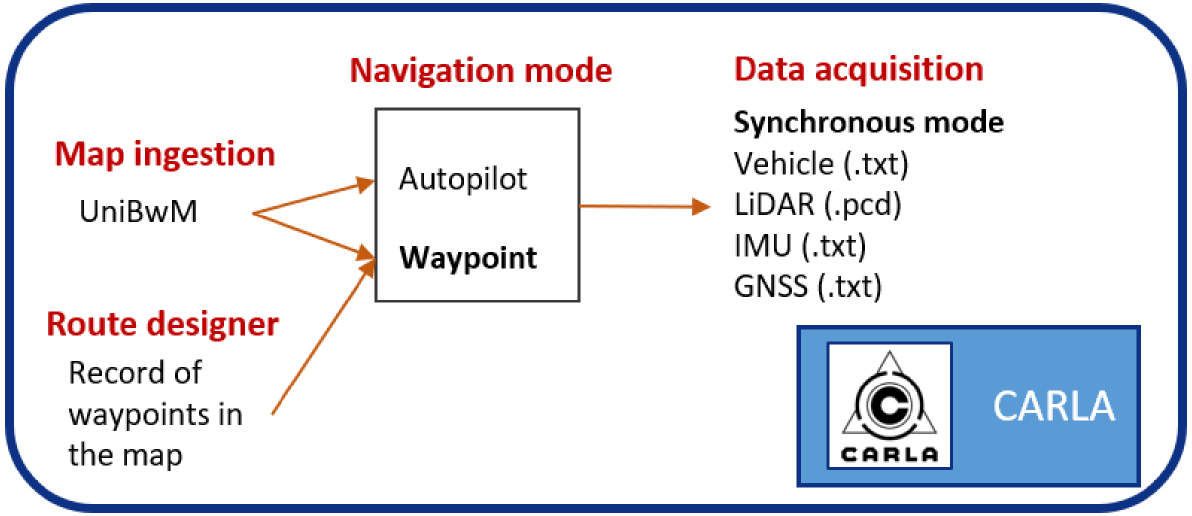
→

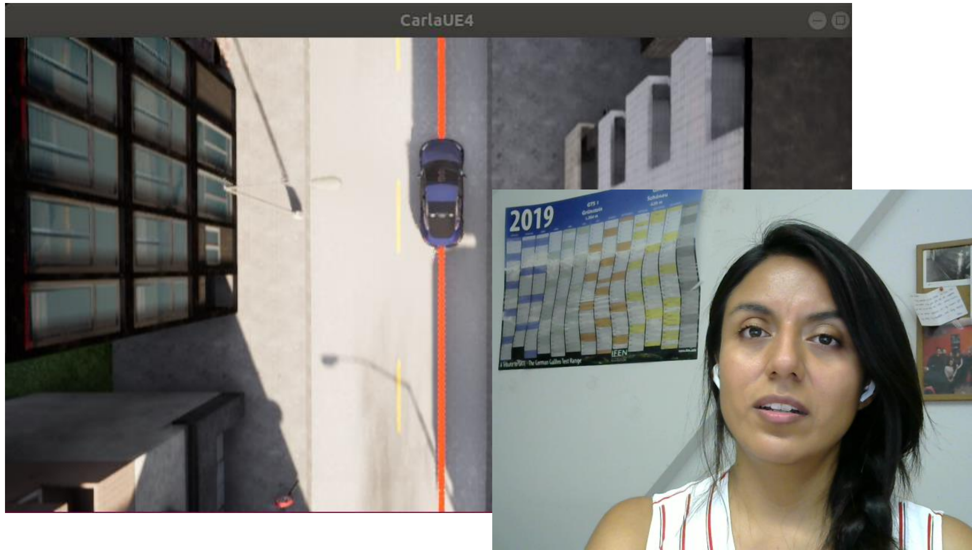
Exporting map

OpenDRIVE file (road network information)
FBX file (mesh of the 3D map)

Trajectory generation and data acquisition

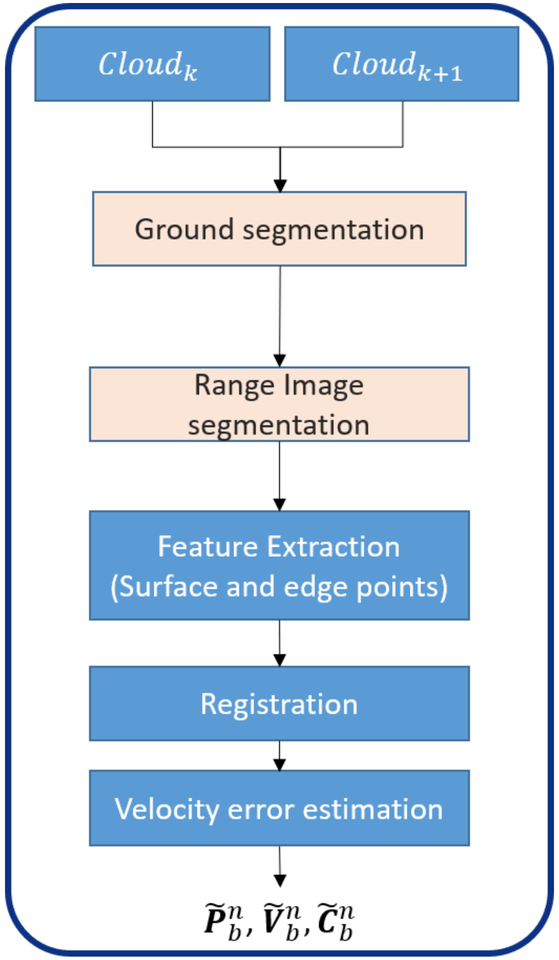
- Trajectory: Route designer + Follow waypoints
- Data acquisition:
  - CARLA -> client-server architecture
  - Synchronization -> fixed step between two simulation moments
  - LiDAR data and state of the car
- LiDAR configurable parameters:
  - FOV (H+V), max range, no. channels, noise, attenuation coefficient, drop-off (general rate/ intensity based)



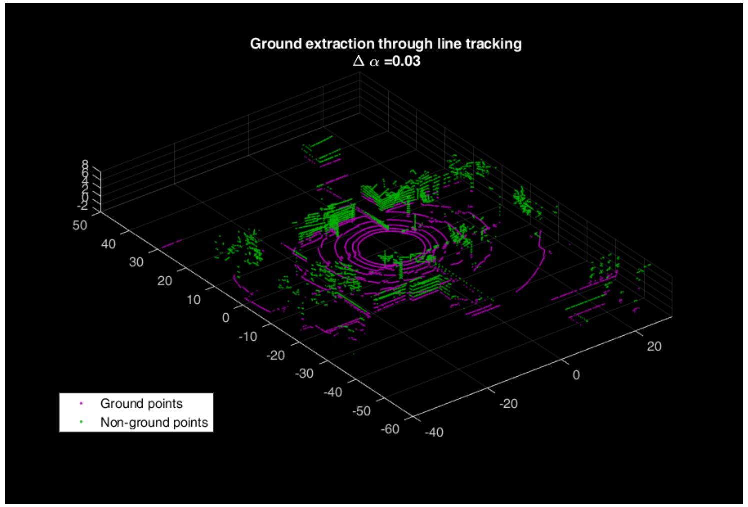


LiDAR processing

Description of each of the modules that compose the LiDAR processing and construction of the LiDAR update



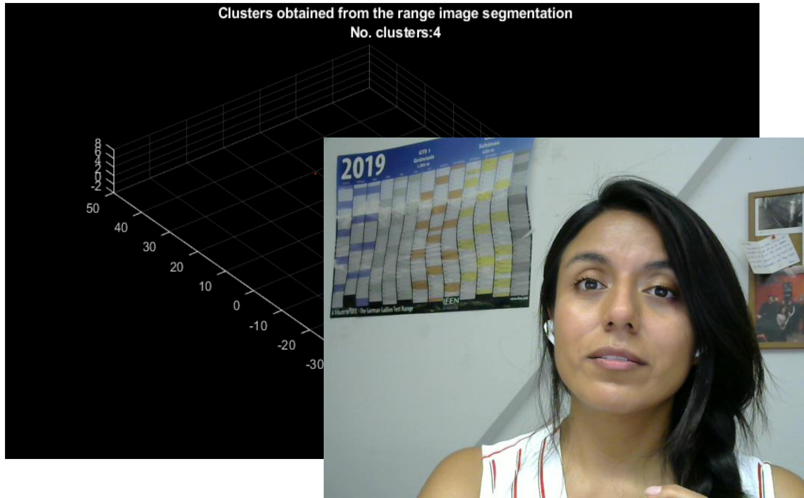
Ground segmentation

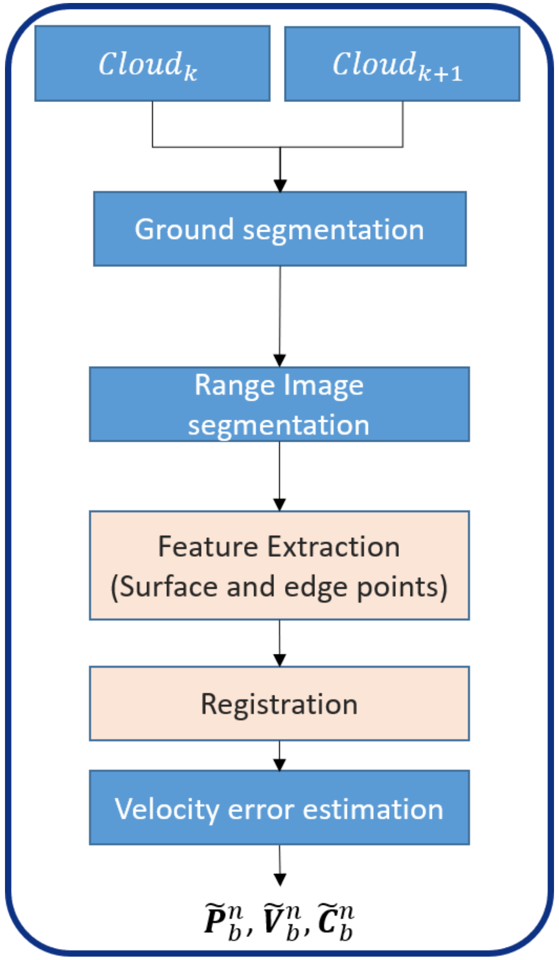


- Using line tracking on prototype points from a 2D dataset, after reducing the dimensionality of the point cloud.
- Targeted for outdoor scenarios (flat & slopped terrain and transitions between them)
- RT capable and only depends in 2 parameters

Range image segmentation

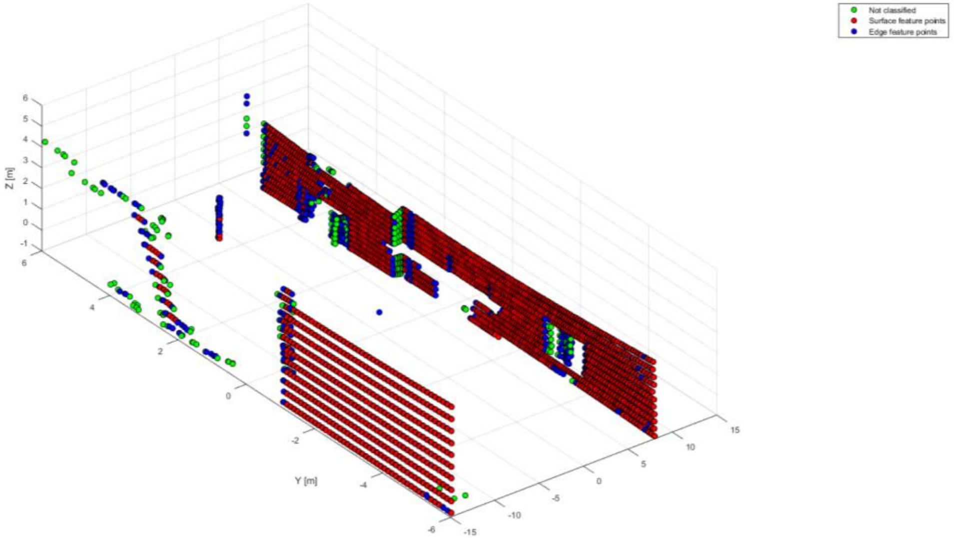
- Based on BFS using a N4 neighborhood and using a depth angle threshold (vertical and horizontal) the image is labeled to distinguish different objects in the scene.
- Working on 2D images allows faster computation
- One can apply methods from image processing or AI





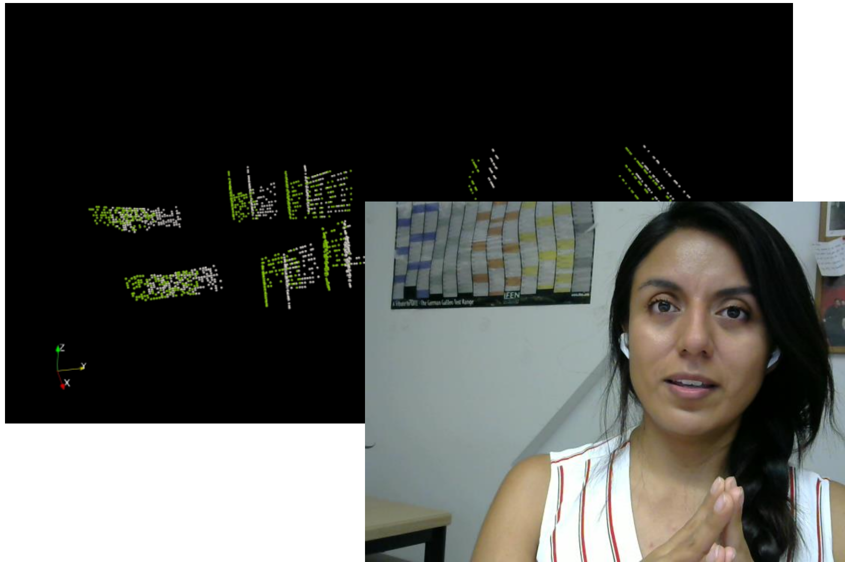
Feature Extraction

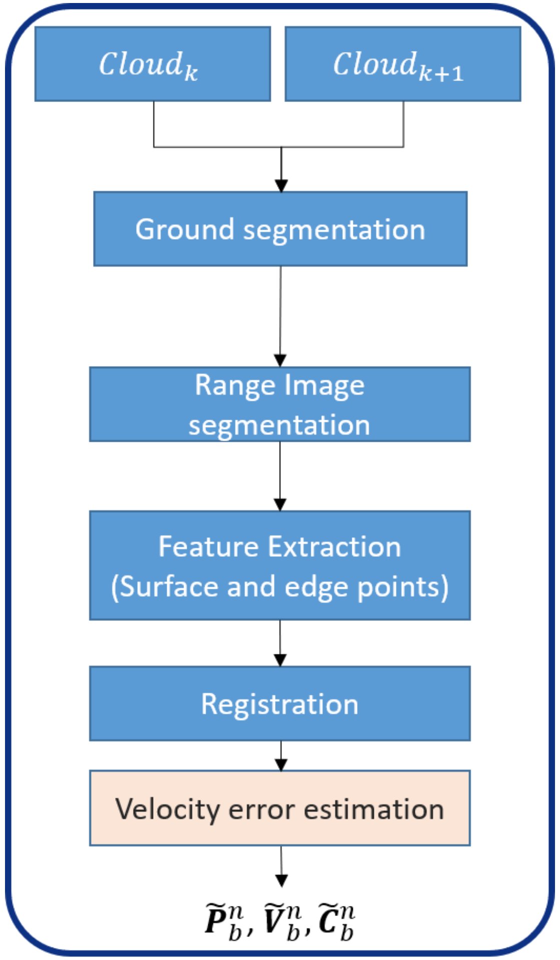
- Based on the curvature value, surface and edge points are detected
- Structural elements (walls) and vertical elements are detected and extracted



Registration

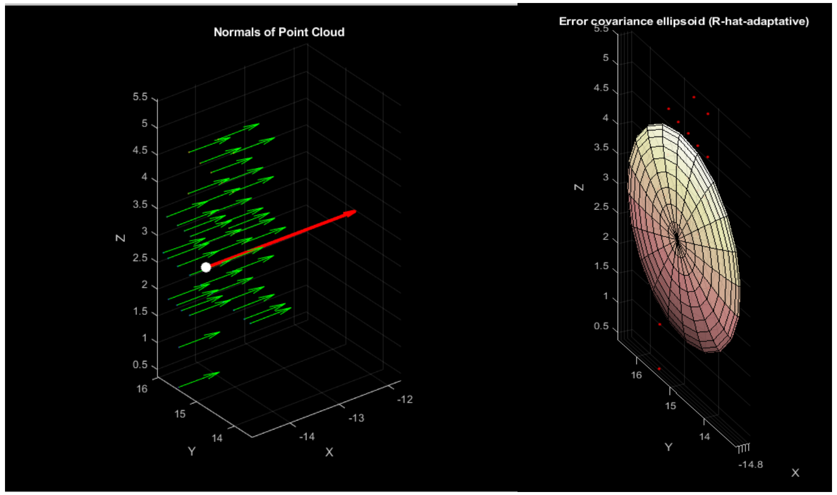
- Applied to the final point cloud consisting in clusters obtained in feature extraction
- ICP: point to plane error minimizer, with surface normal outlier filter and trimmed distance outlier filter



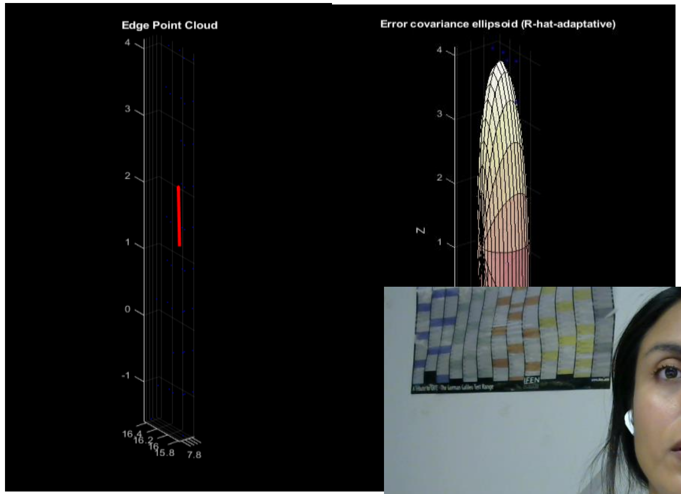


Velocity error estimation

- The position error is model as multivariate Gaussian distribution whose covariance matrix is characterized based on the feature location and orientation wrt to the LiDAR.
- Each structural feature contributes reducing position error in the direction of the corresponding surface normal
- Each vertical feature reduces position error in the directions perpendicular to the edge vector
- The individual contributions of all features covariances are combined to get the positioning error covariance matrix. And from there one can also derive the estimated velocity error



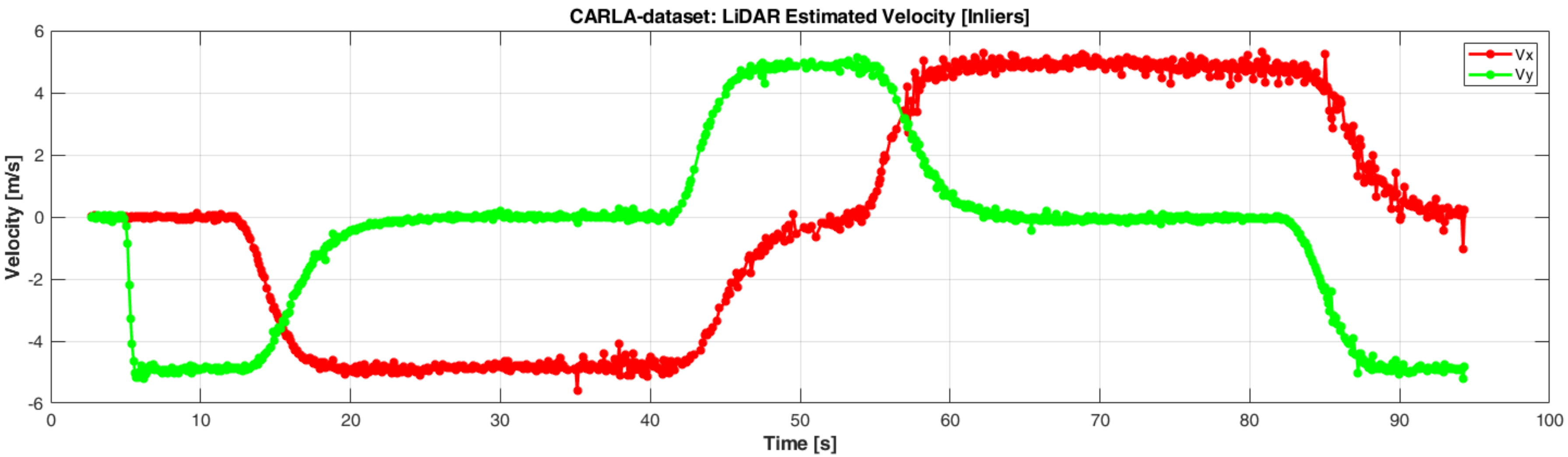
Covariance matrix belonging to a structural feature

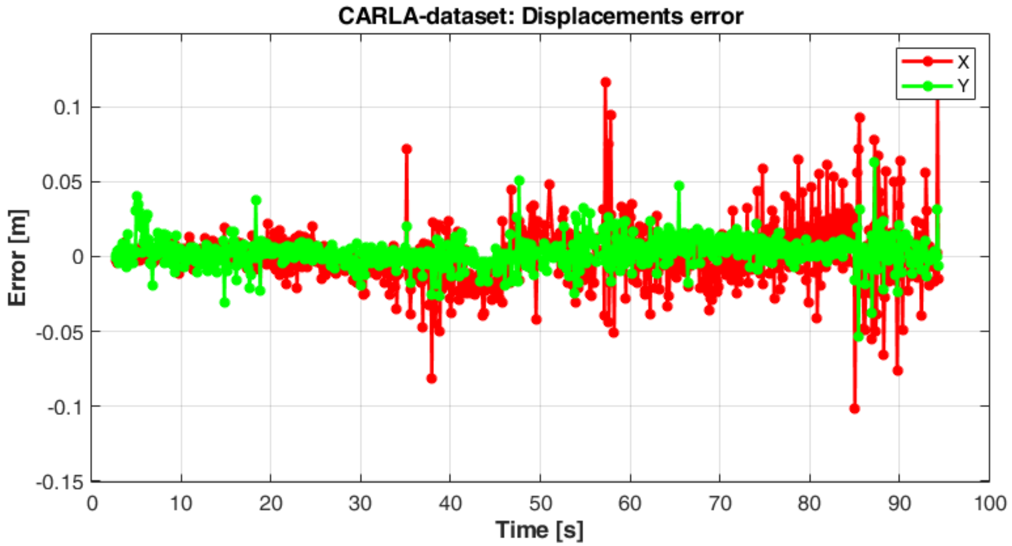


Covariance matrix bel
vertical feature

LiDAR odometry

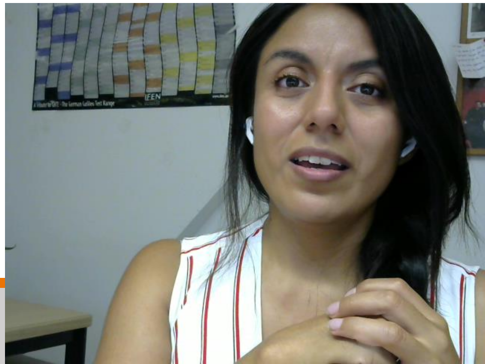
LiDAR odometry

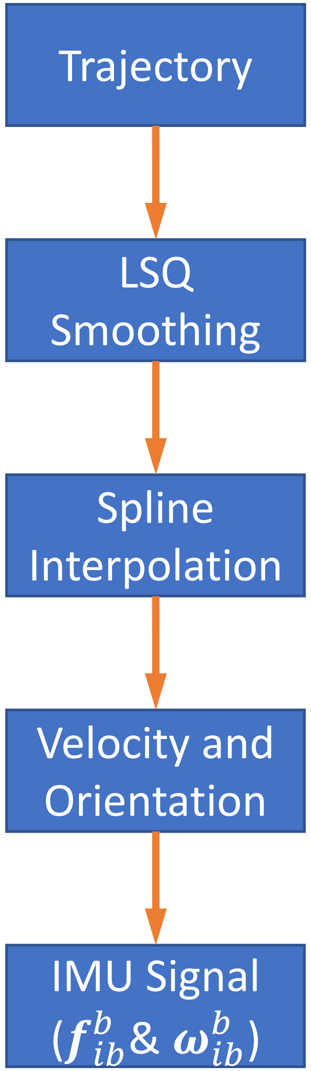




Trajectory-based IMU Simulator

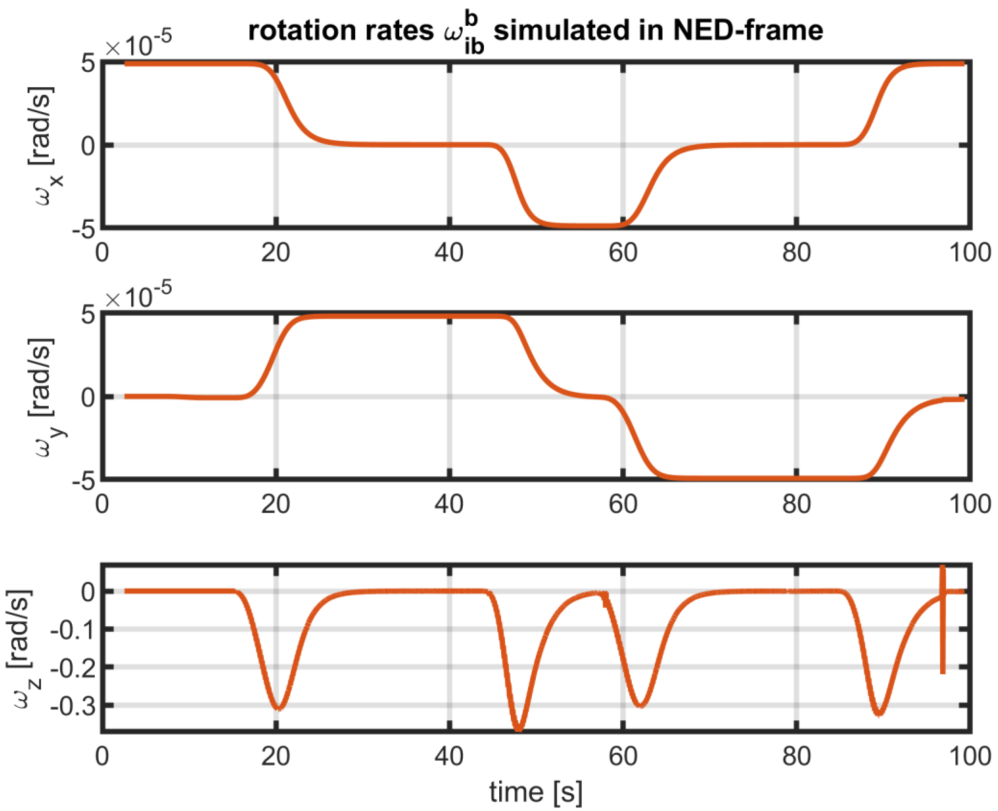
Simulation methodology and generated data

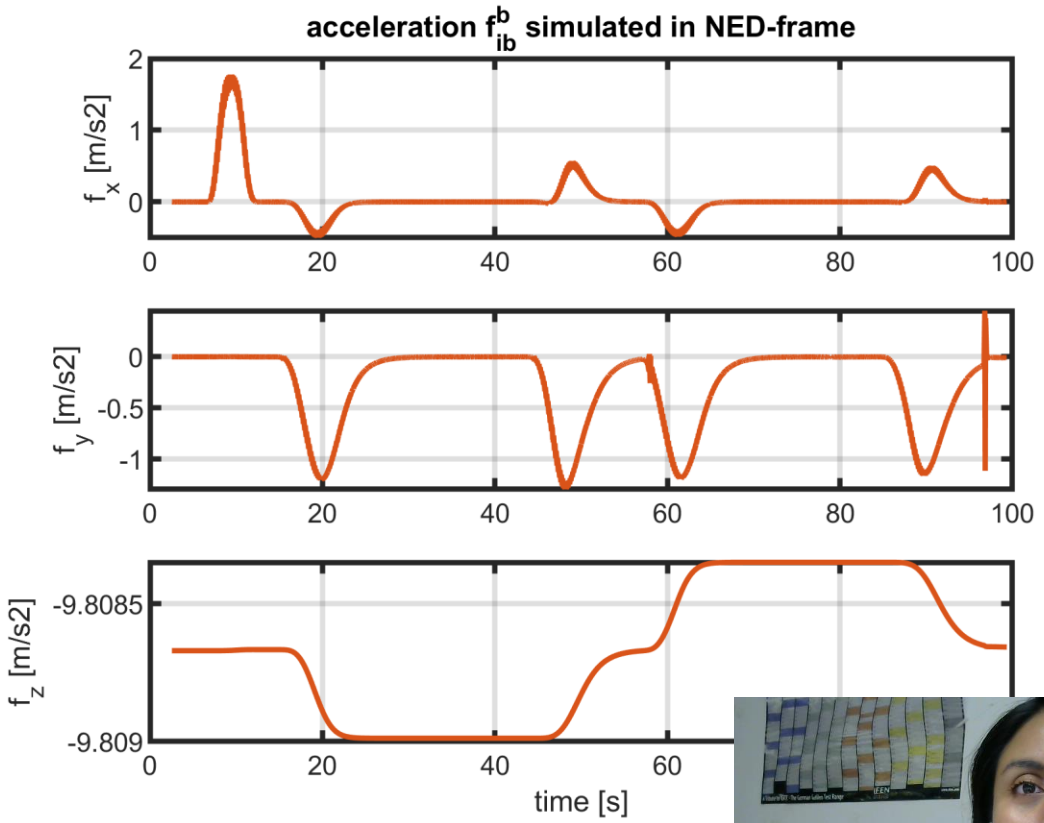




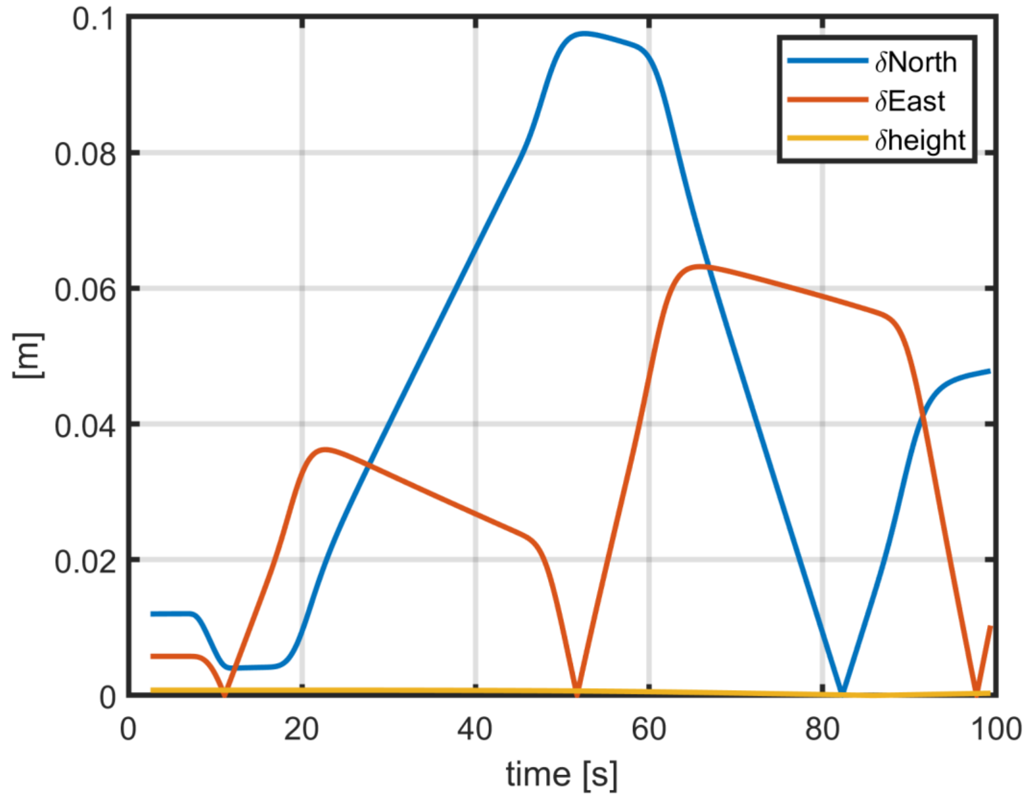
- Generation of error-free IMU observation starting for a given georeferenced trajectory (e.g. from CARLA)
- Advantage:
  - Intuitive and easy design
  - Input trajectory can be provided from everywhere, e.g. from google maps
  - Account for the local gravity change
  - Errors can be simulated and added separately
  - Can be used for both short- and long-dist trajectories

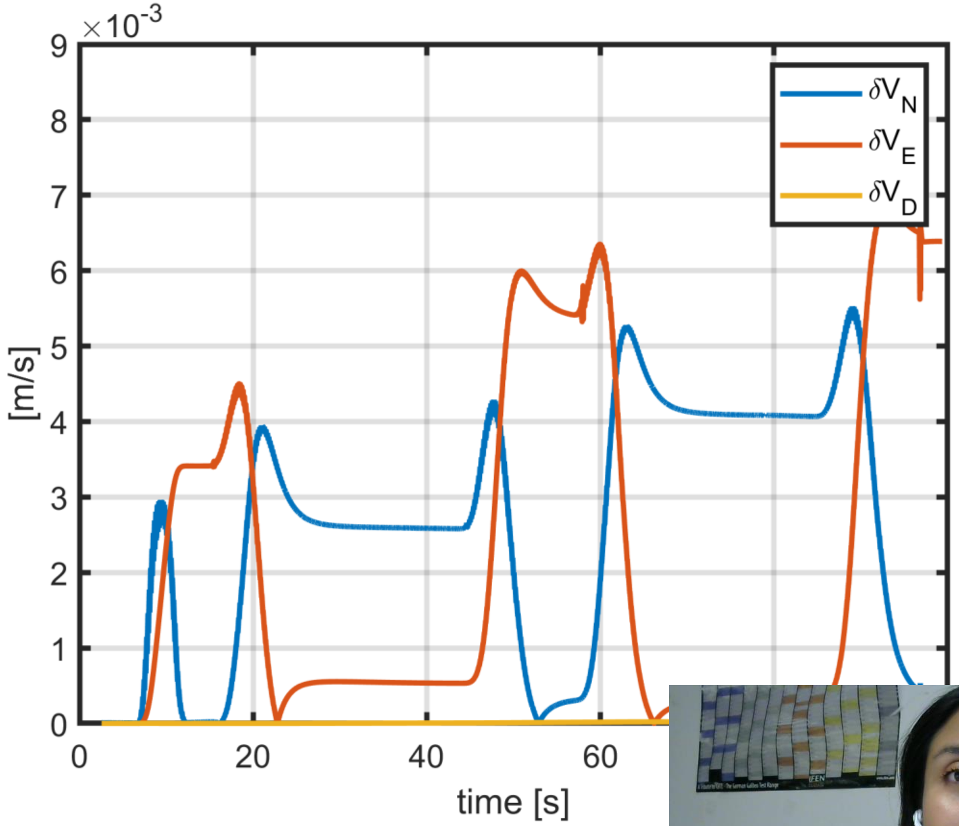
Simulated error-free IMU observation

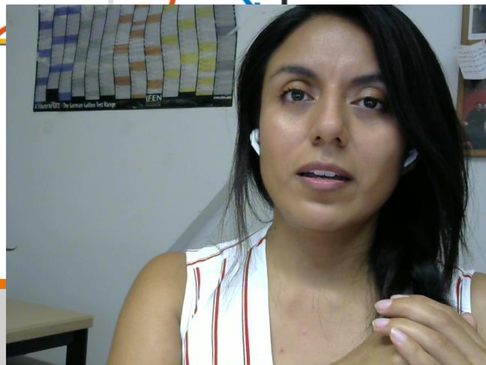




Closed-loop Strapdown error





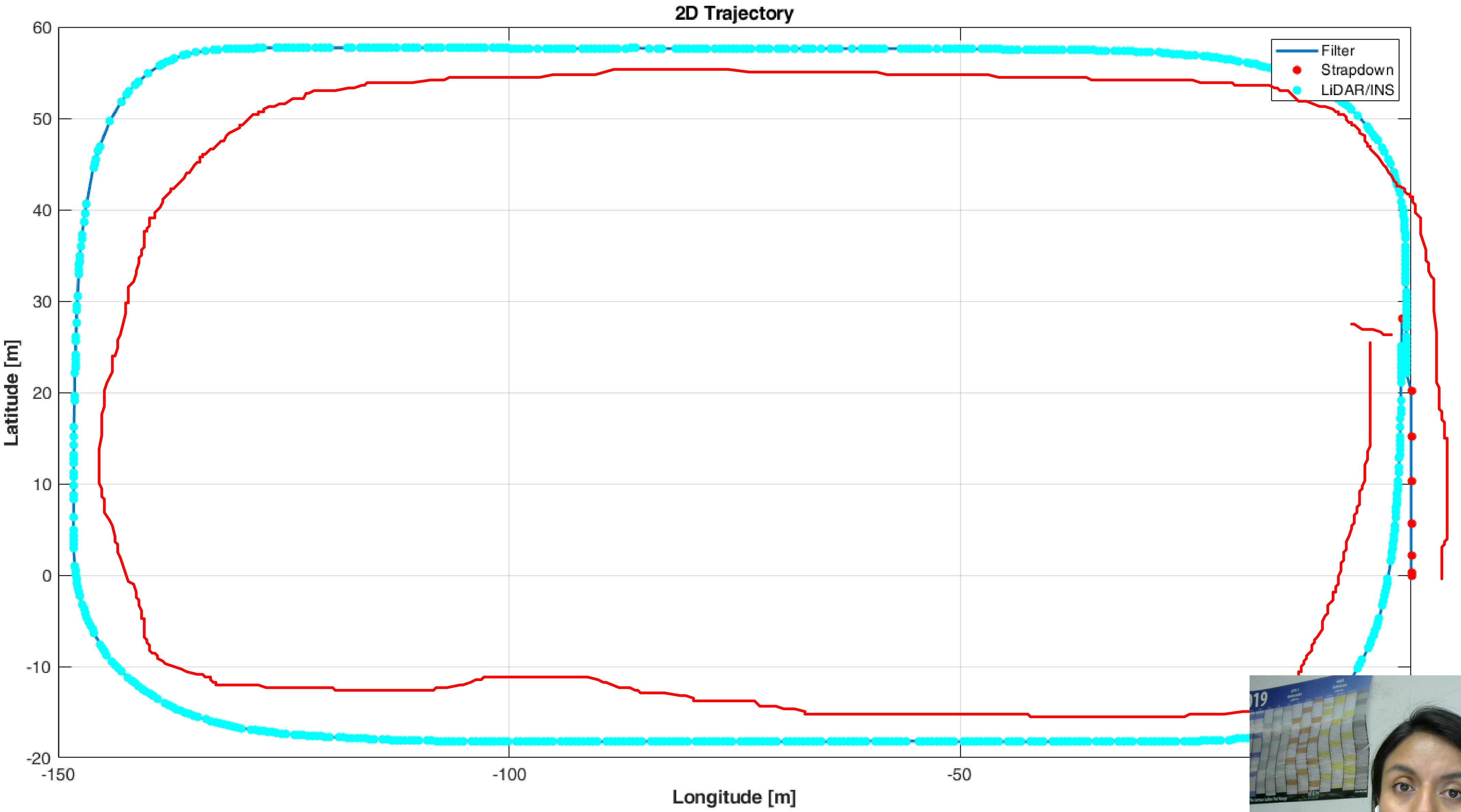


GNSS/INS/LiDAR EKF

Configuration of our filter to process IMU and LiDAR data

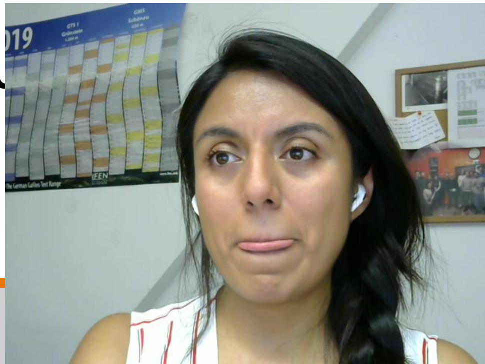
EKF setup

- Static phase for initialization of filter and measurement synchronization
- We assume that the filter has already converged due to previous RTK fixed position updates
- This is followed by several seconds of IMU free-run until the first LiDAR velocity update is introduced
- The PL computed in the LiDAR module is used as measurement accuracy for LiDAR velocity filter update.
- The z velocity in the vehicle frame is set to zero and assumed to be very accurate
- Process noise values were set so the filter accepts every incoming velocity update


2D Trajectory
Filter
Strapdown
LiDAR/INS
Latitude [m]
Longitude [m]
60
50
40
30
20
10
0
-10
-20
-150
-100
-50

Outlook

- Change error models of the sensors: different quality graded IMUs and LiDARs
- Use estimated yaw to minimize errors and accelerate the convergence in the registration module, specially when the car takes turns in joints.
- Test impact of synchronization errors, time offsets and drop-off of LiDAR point clouds
- Testing of processing point clouds in a lower rate
- Test our own developed maps
- Simulate a more realistic car behavior and populate the simu with realistic urban traffic conditions



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