Exploring Cooperative Positioning and Dynamic Base Stations for Potential Vehicular Positioning Accuracy Improvement: A Comprehensive Approach

Paper Authors:

Tânia Guedes, BOSCH, email: tania.guedes@pt.bosch.com

Fabricio Botelho, BOSCH, email: fabricio.botelho@pt.bosch.com **(presenter)**

Ivo Silva, UM, email: ivo@dsi.uminho.pt

Helder Silva, UM, email: hdsilva@dei.uminho.pt

Cristiano Pendão, UM, email: cpendao@dsi.uminho.pt

Cofinanciado por:

COMPETE 2020

PORTUGAL 2020

UNIÃO EUROPEIA
Fundo Europeu
de Desenvolvimento Regional

IARIA

Universidade do Minho

BOSCH

IARIA Congress 2024
Presenter Biography

Fabricio Botelho, M.Sc.

- **Current Position**: Software Engineer at Bosch Car Multimedia, Portugal
- **Previous:** Hardware/Software co-design engineer at Bosch @ADAS Sensors,
- **Education:**
    - M.Sc. in Electronical and telecommunications engineer at University of Aveiro, Portugal
- **Research Interests:**
    - Embedded systems;
    - Hardware Co-design;
    - Artificial Intelligence for autonomous systems;
    - Cooperative environment systems;
- **Contact Information:** fabricio.botelho@pt.bosch.com

IARIA Congress 2024
Research Interests and Current Project

Research Interests:

- Automotive Sensor Systems;
- Autonomous Driving Functionalities (ADAS);
- Research and Development of Advanced Automotive Sensors (HAD).

Current project: NeXtSense

- Researching and developing new innovative concepts for automotive sensors:
  - Inertial Sensors based on Microsystems Technology (MEMS), namely;
  - Safety, Security and reliability for key products (ADAS);
  - Positioning and Connectivity, GNSS based sensors, V2X;
- Partners: Bosch, University of Minho, Portugal.

neXtSense
Safety Connected and Automated Vehicles

IARIA

Universidade do Minho

BOSCH

IARIA Congress 2024
Cooperative Positioning between Vehicles

Technological challenges

- Sensor fusion for enhanced positioning accuracy;
- Urban environment positioning challenges;
- Inertial sensors and other systems for positioning;
- GNSS data sharing from nearby vehicles;
- Adapt a new communication protocol for positioning.

Main goal of the paper:

Explore predicted vehicles as dynamic reference stations, using AI.

Universidade do Minho

BOSCH

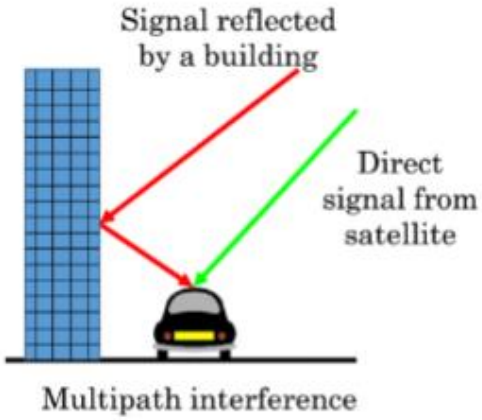
Factors Contributing to GNSS Errors

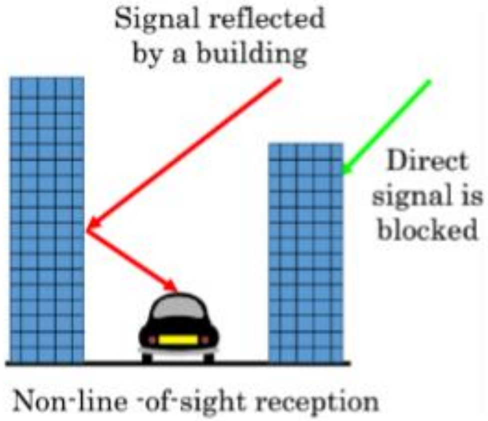
Error Sources in Pseudorange Measurement:

- Ionospheric and Tropospheric Errors
- Satellite Clock Errors
- Receiver Clock Errors
- Ephemeris Data Errors
- Receiver Noise
- Multipath Error
- Dilution of Precision (DOP)

Multipath Errors:

- Most common GNSS error source
- Arises from interference and reception of satellite signals beyond direct line of sight
- Reception of multiple signal replicas (e.g., line-of-sight and reflected signals)
- NLOS, reception of only a reflected signal is more problematic than multipath





Gu, Yanlei et al. "GNSS/Onboard Inertial Sensor Integration With the Aid of 3-D Building Map for Lane-Level Vehicle Self-Localization in Urban Canyon." *IEEE Transactions on Vehicular Technology* 65 (2016): 4274-4287.

IARIA

Universidade do Minho

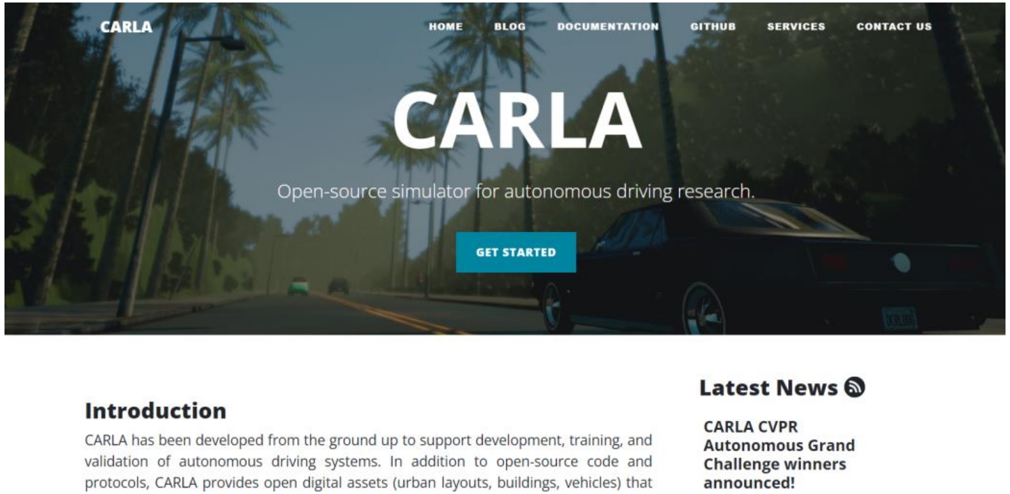
BOSCH

IARIA Congress 2024

Data acquisition, based on Carla Simulator

Key Features:

- **Scalability**: Multi-client control across nodes;
- **Flexible API**: Manage traffic, pedestrians, weather, sensors, etc.;
- **Sensor Suite**: Configure LIDARs, cameras, depth sensors, GPS, ...;
- **Fast Simulation**: Quick traffic simulation without rendering;
- **Map Generation**: Create maps using ASAM OpenDRIVE with RoadRunner;
- **Traffic Scenarios**: Define and run scenarios with ScenarioRunner;
- **Driving Baselines**: Includes AutoWare and Conditional Imitation Learning agentes.



Dosovitskiy, A., Ros, G., Codevilla, F., Lopez, A., & Koltun, V. (2017). CARLA: An open urban driving simulator. In Proceedings of the 1st Annual Conference on Robot Learning (pp. 1–16).

IARIA

Universidade do Minho

BOSCH

IARIA Congress 2024
Data acquisition, based on SatNav toolbox

GPS Support:

- Simulate And Analyze GPS And Galileu Systems

Measurement Generation:

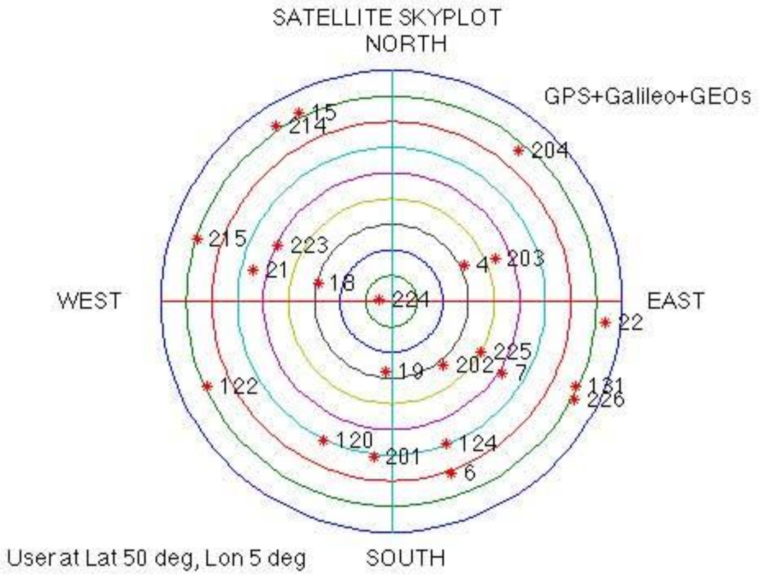
- Generate Pseudo-range And Carrier-phase Measurements

Error Emulation:

- Emulate Multipath, Noise, Troposphere, And Ionosphere Errors

Examples:

- Position Solution;
- Dilution Of Precision Analysis
- Receiver Autonomous Integrity Monitoring (Raim)



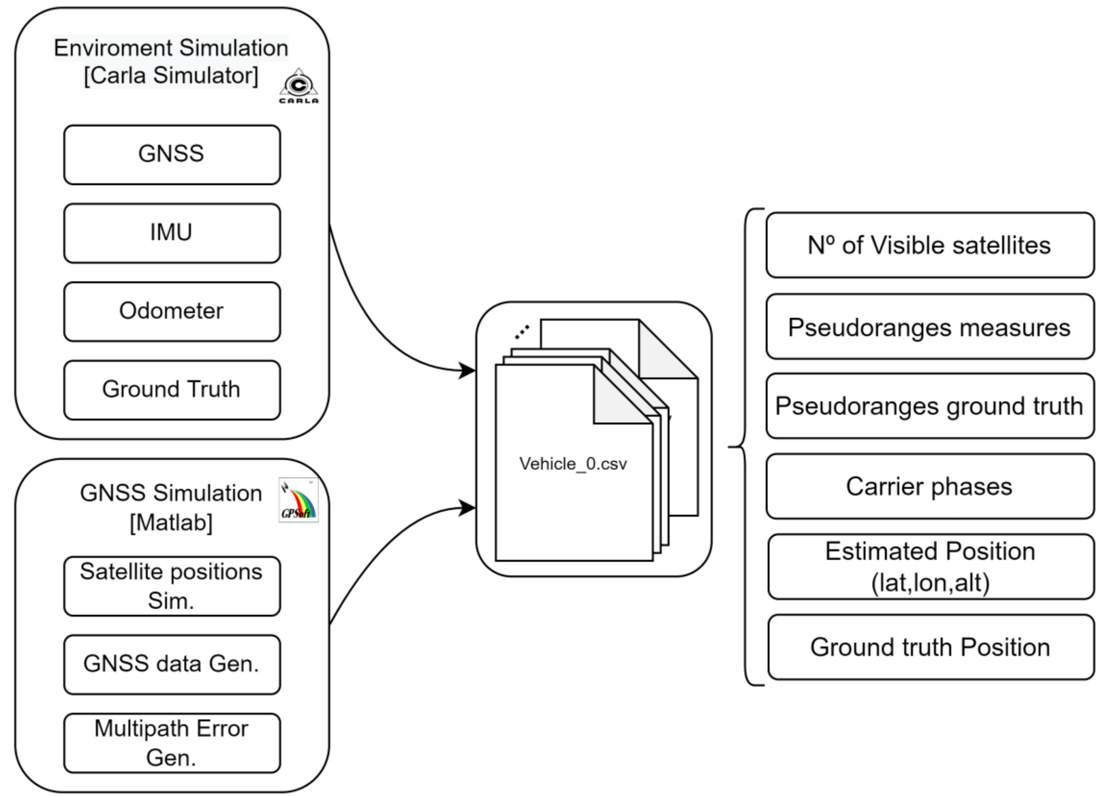
GPSoft | Navigation Simulation and Analysis Software Satellite Navigation (SatNav) Toolbox 3.0 (gpsoftnav.com)

IARIA

Universidade do Minho

BOSCH

IARIA Congress 2024
Data acquisition architecture



*IMU and odometer data were not considered in the next steps.

- Larger town (3-4km)
- Downtown urban area
- Underpasses and overpasses
- Large building under construction
- 20 minutes of simulation
- 6 vehicles

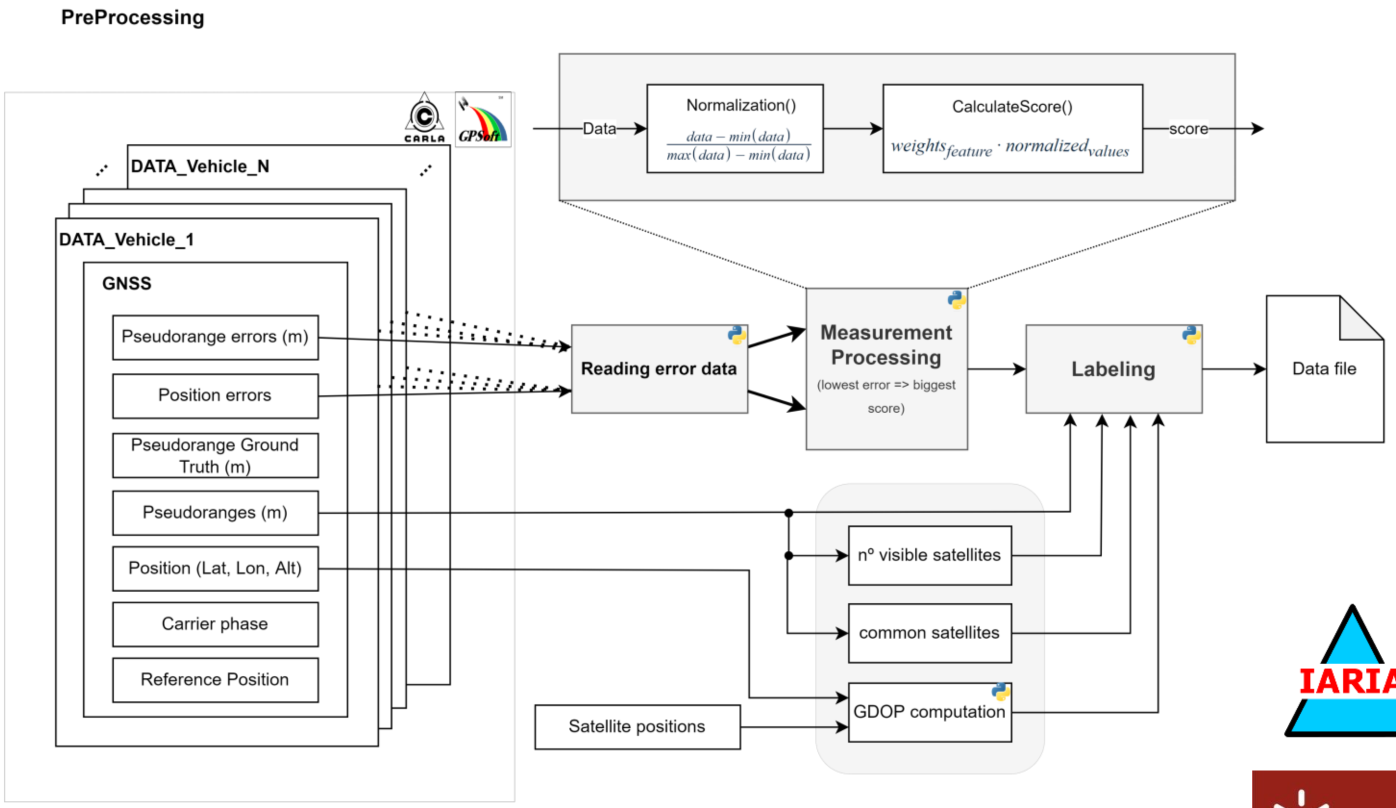
Universidade do Minho

BOSCH

IARIA Congress 2024

Reference Vehicle Selection, Labelling Approach

- **Error Calculation**
  - Pseudorange Errors:
    - Calculated as the difference between computed pseudoranges and ground truth pseudoranges,
  - Position Errors:
    - Obtained by comparing ground truth positions with estimated positions.



- **Score:**

$$Score = 1 - (NormalizedPseudorangeError \times w_1 + NormalizedPositionError \times w_2)$$

IARIA

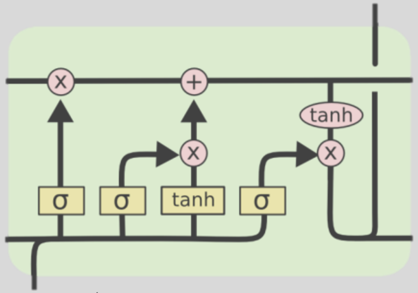
Universidade do Minho

BOSCH

IARIA Congress 2024
AI Algorithms Explored

LSTM (Long Short-Term Memory)

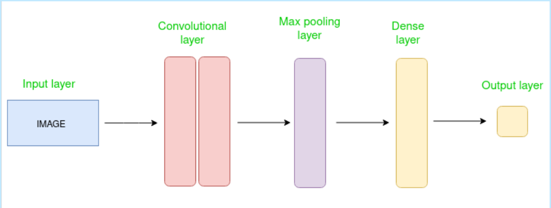
- **Category**: Subtype of Recurrent Neural Networks (RNNs).
- **Specialization**: Deals with sequential or time series data.
- **Feature**: Retains memory from previous inputs to influence current inputs and outputs.
- **Function**: Gates selectively retain or delete information based on input and last hidden state.



Savenhago, Rafael & Ávila, Paulo & Ortolan, Rodrigo. (2022). Arquiteturas de redes neurais e suas aplicabilidades para classificação de sinais EEG para BCI. Revista Brasileira de Computação Aplicada. 14. 55-69. 10.5335/rbca.v14i1.13070.

CNN (Convolutional Neural Networks)

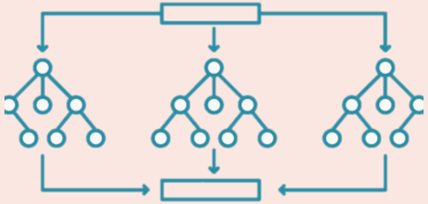
- **Specialization**: Analyzing visual data by detecting and recognizing patterns.
- **Layers**:
  - Convolutional: Responsible for most computations.
  - Pooling: Decrease spatial dimensions while retaining important information.
  - Fully Connected: Combine features for final classification or prediction.



Einführung in Convolution Neural Network - GeeksforGeeks

Random Forest (RF)

- **Type**: Ensemble learning method for classification and regression.
- **Principle**: Aggregating forecasts of multiple decision trees for more accurate results.
- **Voting System**:
  - **Classification**: Uses majority voting rule for final outcome.
  - **Regression**: Uses averaging for stable predictions.
  - **Tie Handling**: Balanced outcome distribution between classes.



Vetor de Random forest line icon. Decision trees symbol. Machine learning technique that's used to solve regression and classification problems. Complex problems solution. Vector illustration, flat, clip art. do Stock | Adobe Stock

IARIA

Universidade do Minho

BOSCH

IARIA Congress 2024

Results using LSTM

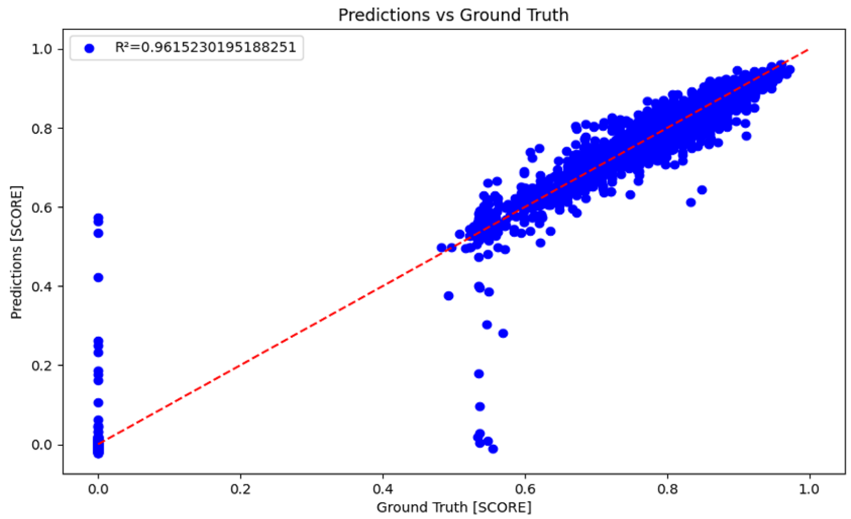
Model ID	Features	MSE	R^2 score
LSTM1.1	F1	0.0002	0.9615
LSTM1.2	F1,F2,F3,F4	0.0109	0.9011
LSTM2.1	F1	0.0037	0.9120
LSTM2.2	F1,F3	0.0021	0.9610

F1: Visible satellites

F2: Common satellites

F3: Pseudoranges

F4: GDOP

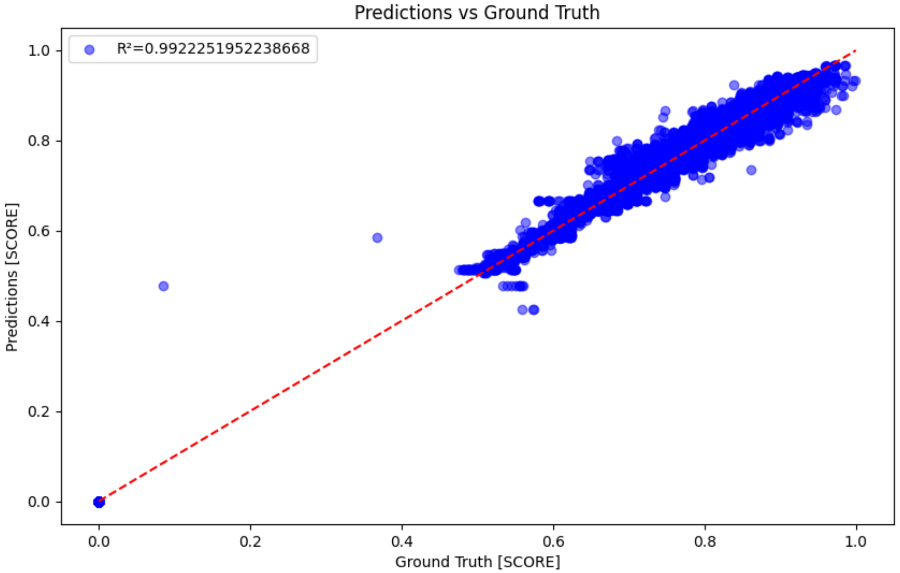


Universidade do Minho

BOSCH

IARIA Congress 2024
Results using CNNs

Model ID	Features	MSE	R^2 score
C1	F1,F2,F3,F4	0.000557	0.984
C2	F1,F2,F3,F4	0.000397	0.988
C3	F1,F2,F3,F4	0.000351	0.989
C4	F1,F2,F3,F4	0.000272	0.992



F1: Visible satellites
F2: Common satellites
F3: Pseudoranges
F4: GDOP

C1: 2 conv layers
C2: 3 conv layers
C3: 4 conv layers
C4: 10 conv layers (achieved best performance)

IARIA
Universidade do Minho
BOSCH

Results using Random Forest

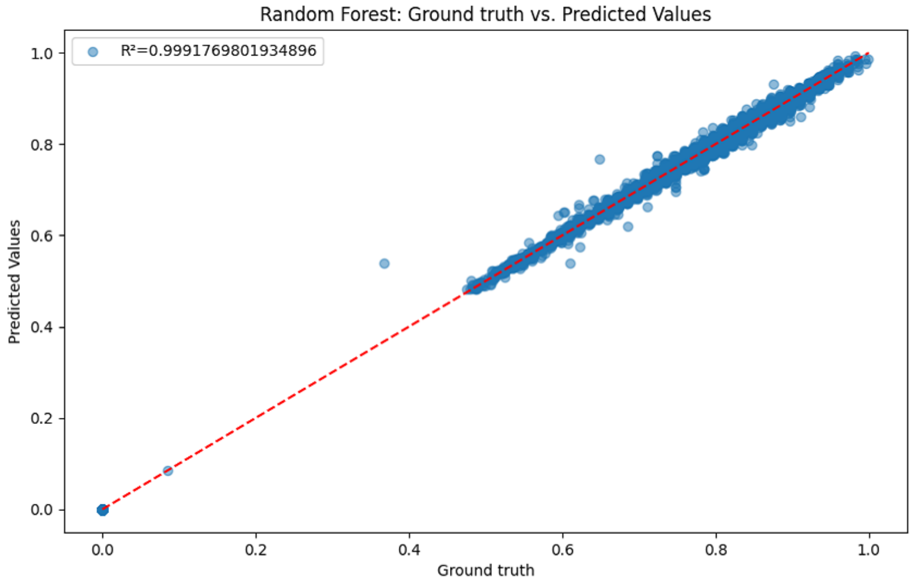
Model ID	Features	MSE	R^2 score
RF1	F1,F4	0.0017	0.9730
RF2	F1,F3,F4	0.0001	0.9993
RF3	F1,F2,F3,F4	0.0001	0.9992
RF4	F2,F3,F4	0.0001	0.9992
RF5	F1,F2,F3	0.0001	0.9992
RF6	F1,F3,F4	0.0001	0.99956

F1: Visible satellites

F2: Common satellites

F3: Pseudoranges

F4: GDOP



Universidade do Minho

BOSCH

IARIA Congress 2024

Conclusion

- **Dynamic Reference Stations:** Determined possible vehicles to act as dynamic reference stations;
- **Promising Results:** GNSS data demonstrated potential with these algorithms, despite existing limitations;
- **Challenges:** Dataset completeness and GNSS data issues for non-visible satellites need addressing;
- **CNN:** More layers improve performance, best with 10 layers (c4);
- **LSTM:** Simpler models with fewer features can perform well, best with f1 (LSTM1.1);
- **Random Forest:** High performance, best with f1, f3, f4 (RF2), suggests suitability for GNSS data.

Future Work

- **Extended Simulations:** Conduct longer simulations to gather more comprehensive data;
- **Alternative Algorithms:** Explore the use of transformers and Graph Convolutional Networks (GCNs) to handle varying input data sizes;
- **Advanced Labeling Methods:** Implement alternative labeling methods based on cooperative positioning approach.

IARIA

Universidade do Minho

BOSCH

Thank you!

IARIA

Universidade do Minho

BOSCH