Content of 4-WP01 Advanced localization and driver assistance systems for trams

Coordinator of the WP

Czech Technical University, Faculty of Electrical Engineering, prof. Ing. Vladimír Havlena, CSc.

Participants of the WP

Skoda Digital, Dr. Ing. Daniel Pachner

FEE CTU, Dept. of Control Engineering, doc. Ing. Zdenek Hurak, PhD.

FEE CTU, Dept. of Cybernetics, doc. Radim Šára

CIIRC CTU, Dept. of Industrial Informatics, Dr. Ing. Michal Sojka

FAS UWB, Dept. of Cybernetics, doc. Ondřej Straka

Main Goal of the WP

Design of reliable, resilient localization system based on fusion of GPS, IMU, odometry, Lidar and other data, fully integrated with on-board real time data sources. Design of a set of advanced driver assistance systems, particularly anticollision system.

Partial Goals for the Current Period

Selection of sensors and on-board unit, design of core algorithms, collection of data and evaluation of core algorithms on simulated and real data.

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverables

- 4-WP01-001 | Sensor head demo implementation, G-funk
  Due 12/2025 | CTU FEE 0.4 | UWB FAS 0.2 | Skoda Digital 0.4 |
- 4-WP01-002 | Core fusion algorithms for advanced position estimation, O
  Due 12/2025 | CTU FEE 0.4 | UWB FAS 0.2 | Skoda Digital 0.4 |
- 4-WP01-003 | Enhanced algorithms for advanced position estimation and situation awareness, O
  Due 12/2025 | CTU FEE 0.4 | UWB FAS 0.2 | Skoda Digital 0.4 |
- 4-WP01-004 | Rapid prototyping platform for sensor head implementation, O
  Due 12/2024 | CTU FEE 0.1 | CTU CIIRC 0.4 | UWB FAS 0.1 | Skoda Digital 0.4 |
- 4-WP01-005 | Periodic system demo / performance evaluation of sensor head operation, O
  Due 12/2025 | CTU FEE 0.4 | UWB FAS 0.2| Skoda Digital 0.4 |
- 4-WP01-006 | Reporting and dissemination, O
  Due 12/2025 | CTU FEE 0.4 | UWB FAS 0.2 | Skoda Digital 0.4 |

- 4-WP01-007 | Programmable hardware platform for tests of vehicle communication channels
  Due 12/2025 | CTU FEE 0.3 | SkodaAuto 0.6 | TUV 0.1 |
- 4-WP01-008 | Dynamic multimodal transport optimization – specification of optimized means of transport
  Due 12/2025 | CTU FEE 0.5 | CTU FME 0.5 |

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-001 (Gfunk, Daniel Pachner, Skoda Digital)

Sensor head demo implementation

Sensor head software will be focused on algorithms for decimeter scale localization with high integrity and availability, and simultaneous-localization-and-mapping (SLAM) system based on map-aided, surface-aided (Radar, Lidar, video) for trams following predefined routes. Obstacle detection and mapping, estimating their position and velocity will be based on fusing relative measurement with absolute position/velocity estimates.

Due 12/2025 | CTU FEE 0.4 | UWB FAS 0.2 | Skoda Digital 0.4 |

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-001

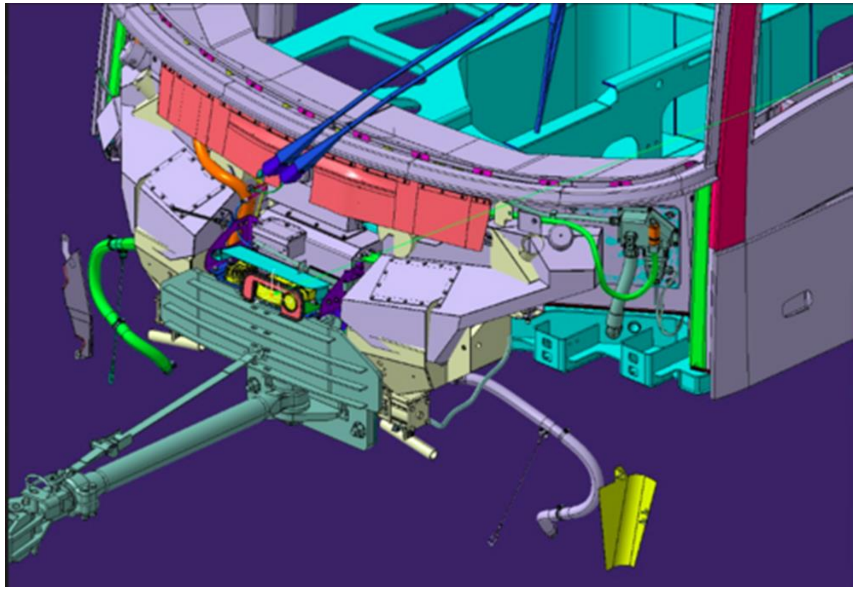
Sensor head demo implementation

- Goal
  - Implement and validate advanced multiple sensor head for tram anti-collision system
- State
  - Sensor head design finalized – Lidar, Camera and IMU on a single mechanical platform (2 variants / 2 LiDARs)
  - Additional HW & SW equipment installed or under development
  - Sensor head implemented for 15T and 34T Škoda trams
  - Implementation for 39T (Ostrava) and 40T (Plzeň) ongoing
  - Two trams equipped with sensor head in Prague with two different Lidars
  - Sensor head certified, commissioned, tested
  - Authority approval (Drážní úřad) is being processed
  - New rail approved embedded computer under development

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-001

Sensor head demo implementation



Sensor head implementation for Prague 15T tram

- Placed below the windshield (pros and cons considered)

Assembly also includes

- Ethernet connection to vehicle data network
- Internet connection
- GNSS antenna and receiver
- Powerful Embedded Computer
- Vehicle Control Unit interface
- Traction Control Unit Interface
- Vehicle display interface
- Buzzer for alarms
- Alarm cancel button

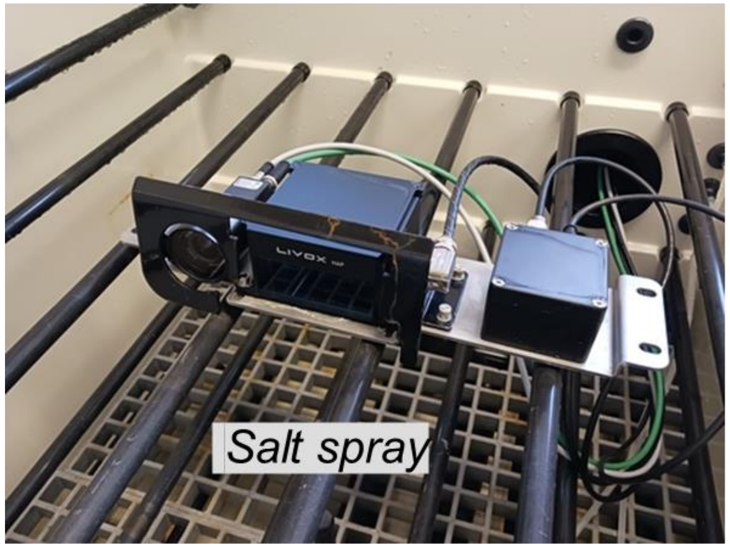
Content of 4-WP01 Advanced localization and driver assistance systems for trams

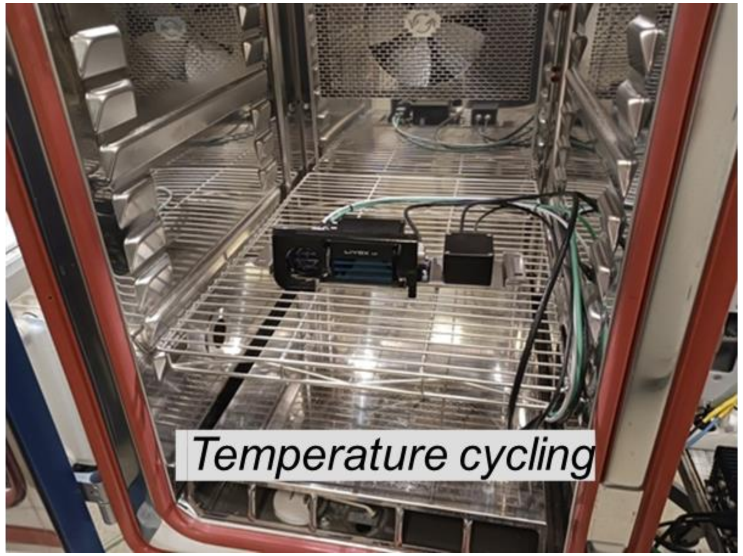
Deliverable 4-WP01-001

Sensor head demo implementation

EN 50155:2021 Railway applications - Rolling stock - Electronic equipment **test passed**

- Low and high temperature, temperature cycling
- Humidity, salt spray
- Electromagnetic compatibility, vibrations



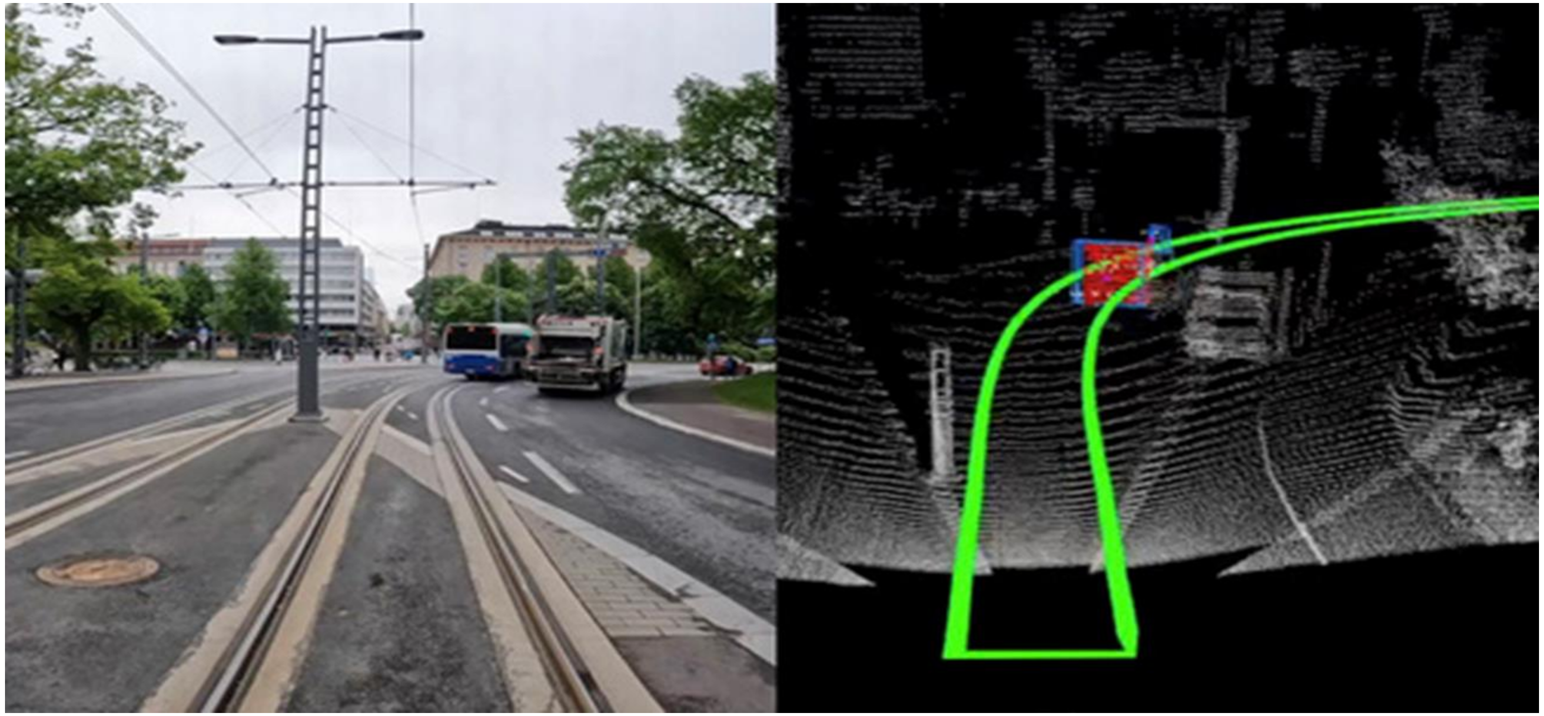


Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-001

Sensor head demo implementation

Camera / Lidar views side by side (Tampere)



Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-002 (O, Zdenek Hurak, FEE CTU)

Core fusion algorithms for advanced position estimation

This result will cover the development of

- motion model for estimation incl. sensor noise
- core fusion of GNNS, IMS, odometry, RFID points (balises)
- fusion with map data, 1D real-time position/speed estimation on a fixed track
- partial smoothing, Sav-Gol filter, 1D delayed position/ speed/acceleration estimation
- final integration with other sensing subsystems
- repetitive map correction

Due 12/2025 | CTU FEE 0.4 | UWB FAS 0.2 | Skoda Digital 0.4 |

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-002

Core fusion algorithms for advanced position estimation

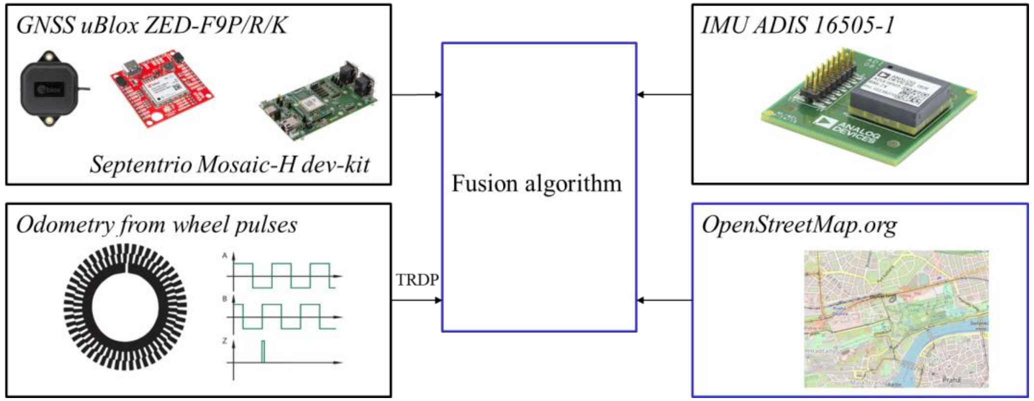
- Goals
  - Core fusion algorithms of GNNS, IMS, odometry and map data, 1D real-time position
  - Validation on real time data
- Activities
  - Selection of the sensors, hardware set up
  - Data acquisition during several experimental rides with a tram
  - First versions of multisensor fusion algorithms for
    - Estimation of position and velocity
    - Estimation of road grade
    - Estimation of delays (synchronization of measurements from individual sensors)

Content of 4-WP01 Advanced localization and driver assistance systems for trams

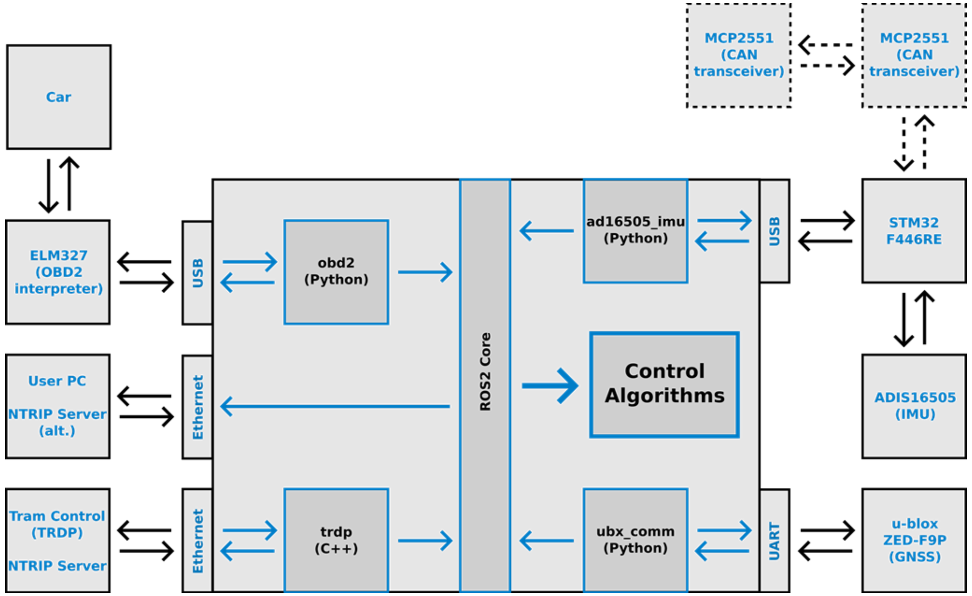
Deliverable 4-WP01-002

Core fusion algorithms for advanced position estimation

Sensors/other data sources



Prototyping platform



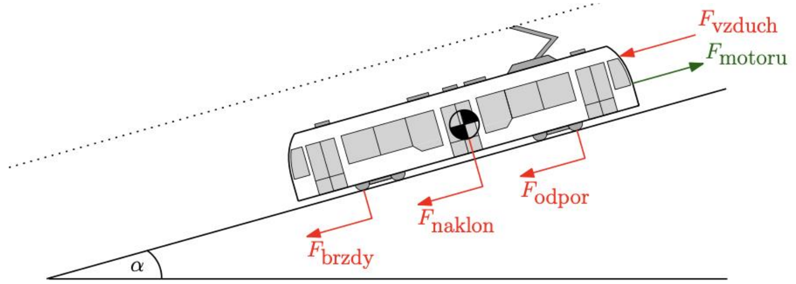
Content of 4-WP01 Advanced localization and driver assistance systems for trams

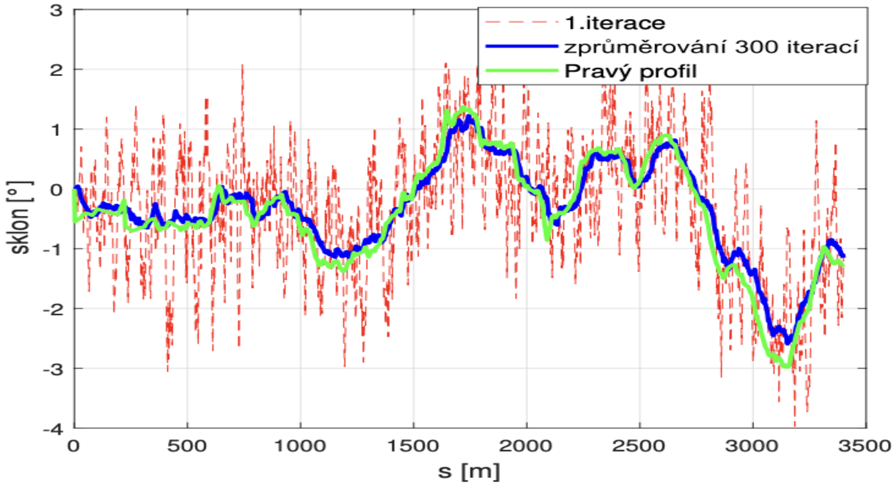
Deliverable 4-WP01-002

Core fusion algorithms for advanced position estimation

First version(s) of multisensor fusion for road grade estimation

- What will it be useful for?
  - (More accurate) prediction of braking distance
  - Input to energy-optimal trajectory optimization (e.g. in combination with V2I-based GLOSA)
- Aren't maps enough?
  - OpenStreetMaps not accurate/reliable enough
  - High-accuracy Digital Elevation Map (DEM) available in some cities
  - Problems with occlusions (trees, bridges, …)





Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-003 (O, Radim Sara, FEE CTU, Ondrej Straka, UWB FAS)

Enhanced algorithms for advanced position estimation and situation awareness

This result will cover the development of

- LIDAR/video subsystem
- Efficient SLAM (Simultaneous Localization and Mapping) module
- Doppler RADAR absolute speed measurement subsystem
- Localization of multiple objects using mutiple sensors with missing / false measurements

Due 12/2025 | CTU FEE 0.4 | UWB FAS 0.2 | Skoda Digital 0.4 |

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-003

Enhanced algorithms for advanced position estimation and situation awareness

- Goals
  - Processing Lidar data from Skoda Digital sensor head
  - Tools for evaluation of minimum set of sensors providing required performance
- Activities
  - LiDAR calibration
  - LiDAR odometry and self-localization
  - HD mapping
  - Navigation in 3D and along track (1D)
  - Simulator of „ground truth" data
  - Sensor error models

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-003

Enhanced algorithms for advanced position estimation and situation awareness

Geometric Perception: Trajectory computed from LiDAR data vs. GPS reference

Note the cumulative error is just rotational

- Robust ICP (in red)
- Motion compensation
- No GPS, IMU in ICP
- No loop closing
- 3 km length
- 11 min drive
- Variable speed, stops

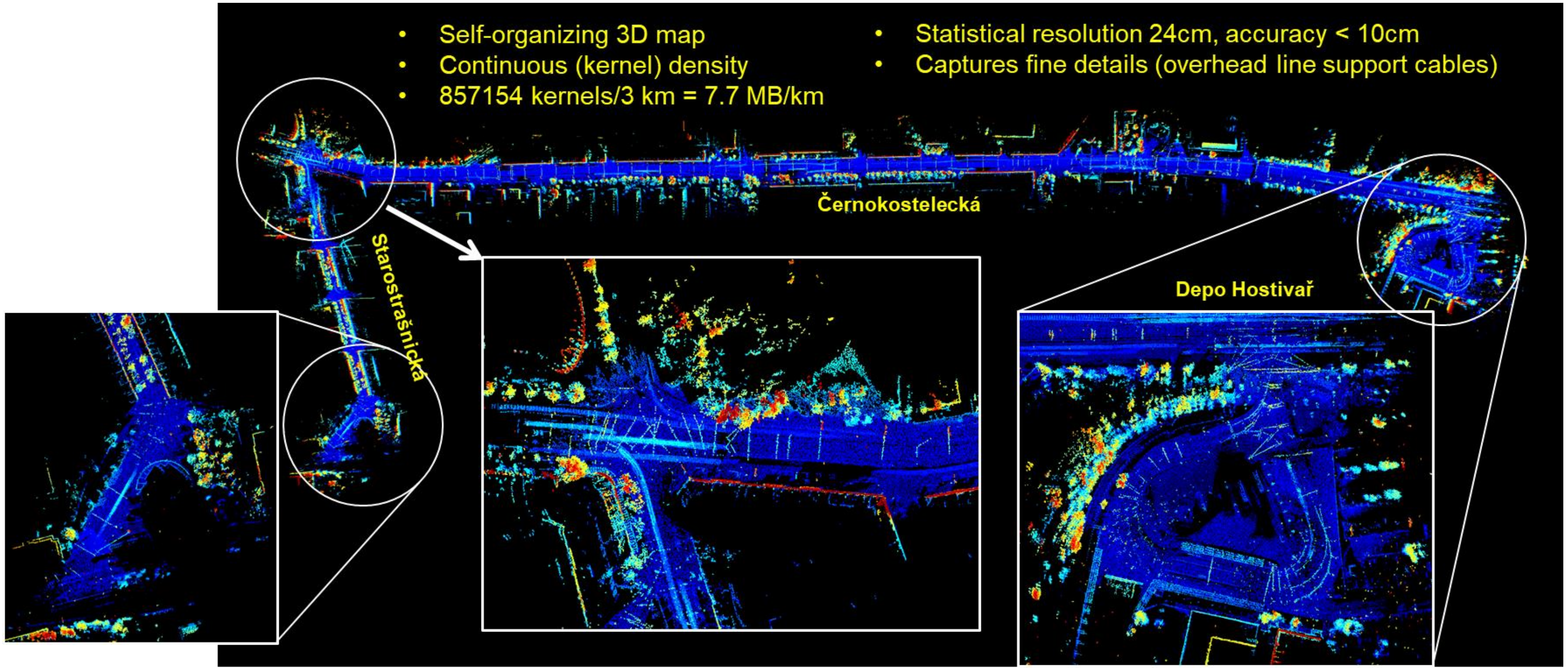
Depo Hostivař

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-003

Enhanced algorithms for advanced position estimation and situation awareness

Geometric Perception: High-Density 3D Mapping from LiDAR data

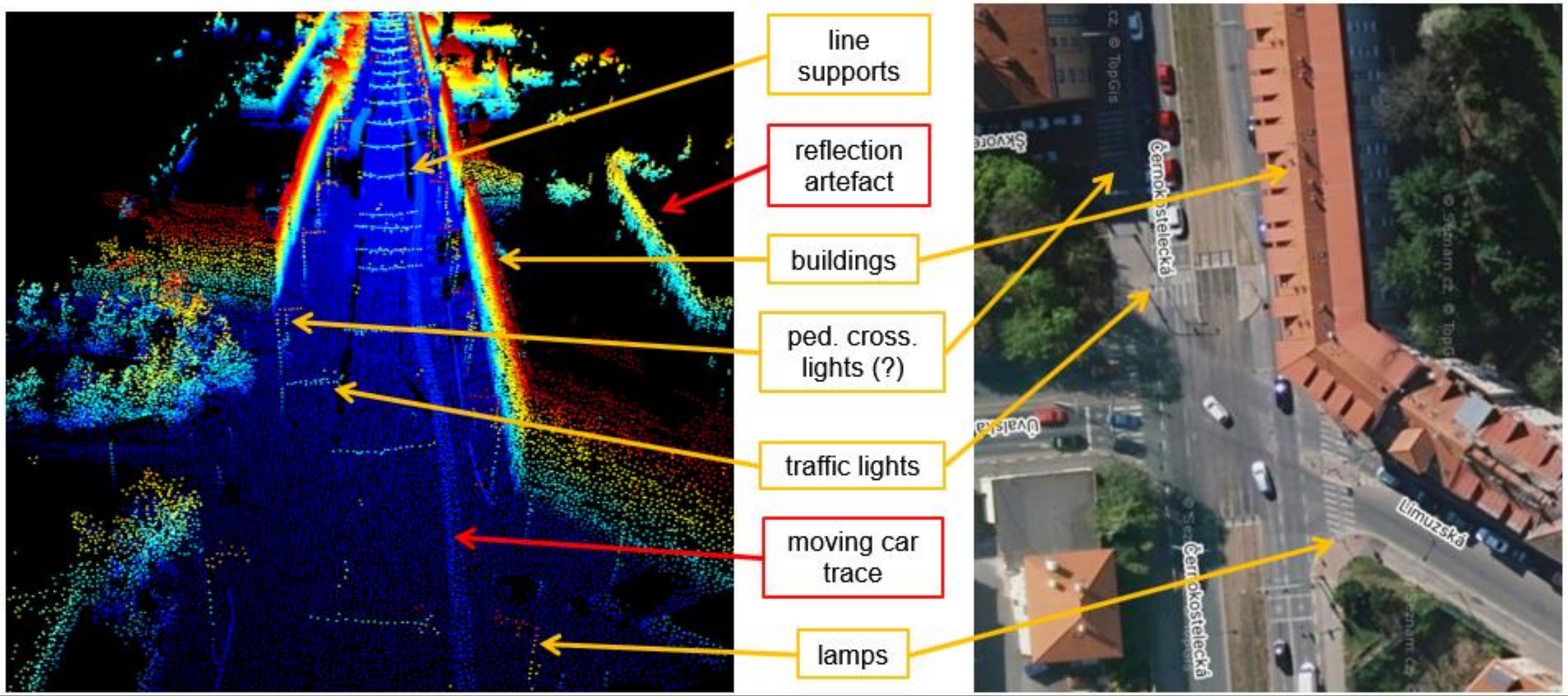


Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-003

Enhanced algorithms for advanced position estimation and situation awareness

Geometric Perception: Infrastructure capture in HD map

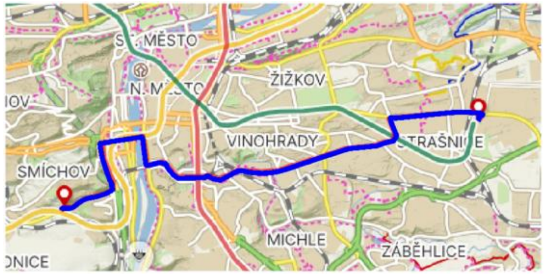


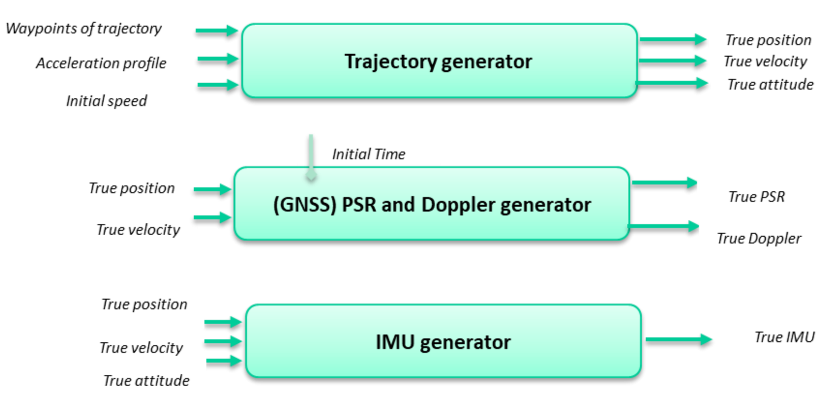
Content of 4-WP01 Advanced localization and driver assistance systems for trams

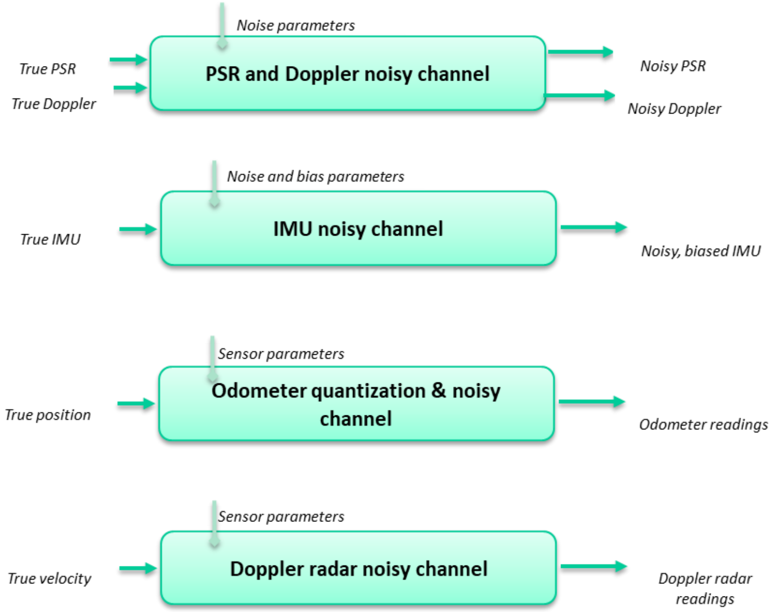
Deliverable 4-WP01-003

Enhanced algorithms for advanced position estimation and situation awareness

Advanced localization techniques – software simulator for testing







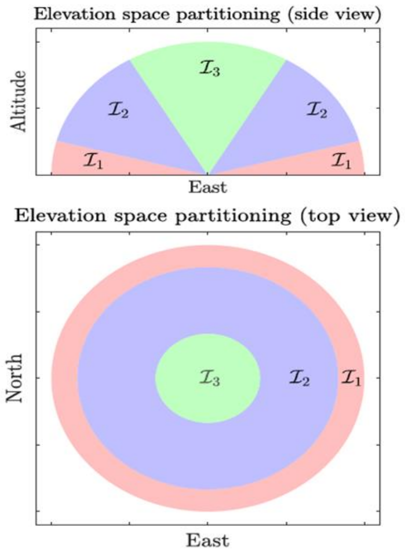
Content of 4-WP01 Advanced localization and driver assistance systems for trams

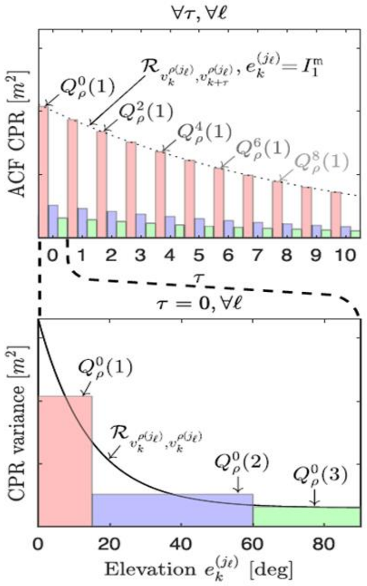
Deliverable 4-WP01-003

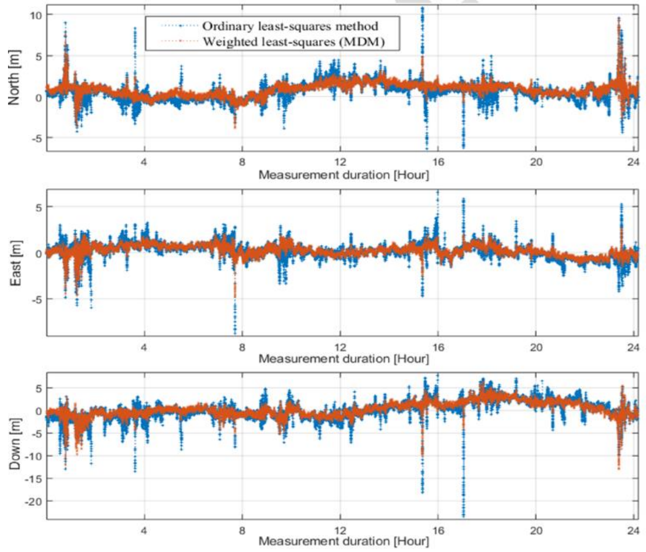
Enhanced algorithms for advanced position estimation and situation awareness

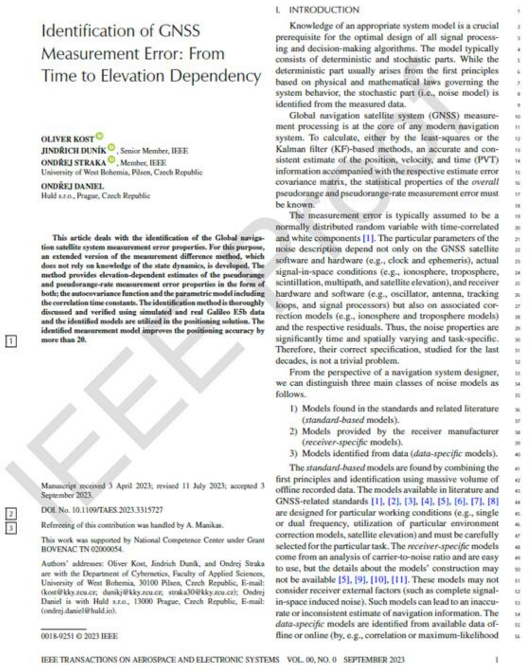
Advanced localization techniques – identification of GNSS receiver noise parameters

20+ % estimation improvement








Identification of GNSS Measurement Error: From Time to Elevation Dependency

OLIVER KOST
JINDŘICH DUNÍK, Senior Member, IEEE
ONDŘEJ STRAKA, Member, IEEE
University of West Bohemia, Pilsen, Czech Republic
ONDŘEJ DANIEL
Huld s.r.o., Prague, Czech Republic

I. INTRODUCTION

IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS VOL. 00, NO. 0 SEPTEMBER 2023

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-004 (O, Michal Sojka, CIIRC CTU)

Rapid prototyping platform for sensor head implementation

Rapid prototyping is considered the most efficient alternative in the development of complex cyber-physical systems, consisting of HW and SW modules. For the task of multiple sensor fusion and obstacle detection, the ROS operation system is selected as the platform of choice. Software modules can be implemented using Simulink Coder environment, with efficient and reliable ROS node target code generation.

Due 12/2024 | CTU FEE 0.1 | CTU CIIRC 0.4 | UWB FAS 0.1 |Skoda Digital 0.4 |

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-004

Rapid prototyping platform for sensor head implementation

- Goals
  - Develop rapid prototyping platform for autonomous driving advanced algorithms (sensor fusion, SLAM, visual localization, object detection & classification)
  - Solution meeting industrial standards
- Activities
  - New custom embedded CPU under development
    - NXP LX2160A 16 cores bases processing unit
    - Rail Operation Certified
  - ROS2 considered as integration environment
    - Organized ROS 2 workshop for all WP partners
    - Discussion of component integration
  - Contributions to the ROS open source ecosystem
    - Minimize the risk of compliance issues

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-004

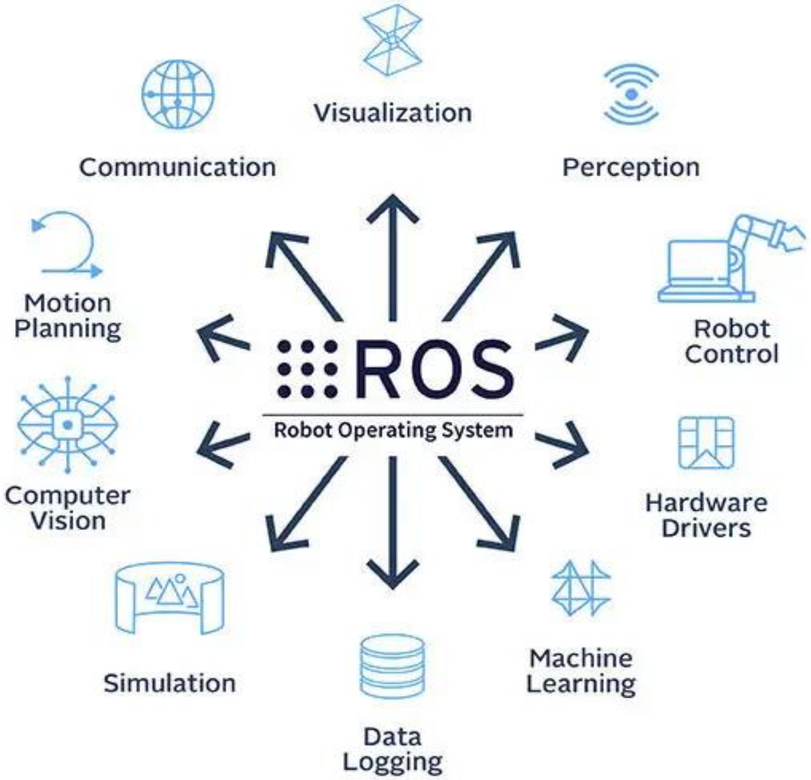
Rapid prototyping platform for sensor head implementation

ROS 2 – open-source framework for robotic applications

- Supports several programming languages
- Allows easy integration of independent components
- Over 1200 SW packages

Supported hardware

- Whatever runs Linux
- Dedicated CPU for Skoda Digital



Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-005 (O, Daniel Pachner, Skoda Digital)

Periodic system demo / performance evaluation of sensor head operation

This periodic system demo/ performance evaluation will provide real-life evaluation of the performance limits of individual generations of the on-board software modules for localization and obstacle detection. It will be planned on 12 month basis. Results will be mapped to requirement specification for the next phase of algorithmic development.

The final demo will provide hard data for the selection of the production level instrumentation and algorithms used in driver assistance / collision avoidance system productization in 2026-2028.

Due 12/2025 | CTU FEE 0.4 | UWB FAS 0.2 | Skoda Digital 0.4 |

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-005

Periodic system demo / performance evaluation of sensor head operation

- Goals
  - Validate advanced multiple sensor head for tram anti-collision system in on-road operation
  - Provide requirement specification for the next phase of algorithmic development
- Activities
  - Running tests in Prague and Tampere
  - Data provided to FEE CTU team
  - Regular meetings with municipal transport opersators

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-005

Periodic system demo / performance evaluation of sensor head operation

State of System Demo Prague

- Collaboration with the tram operator (DP Praha) on line 7
- Until the approval by the authority (Drážní úřad), only the testing without passengers is allowed
- Data collected
  - 1-2 test rides per week with one of the T15
  - Tests in depots
  - Line 16 may be approved soon

Narrow Pass Test

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-005

Periodic system demo / performance evaluation of sensor head operation

State of System Demo Tampere

- Collaboration with the tram operator (Tampere Rapikka, FI) on line 2 and 3
- Sensor head mounted on a 34T vehicle manufactured by TRANSTECH Oulu
- Data collected and available for analyses

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-006 (O, Vladimir Havlena, FEE CTU)

Reporting and dissemination

Interim reports on individual project milestones, publications in journals and conferences, diploma and PhD theses.

Due 12/2025 | CTU FEE 0.4 | UWB FAS 0.2 | Skoda Digital 0.4 |

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-006

Reporting and dissemination

- **Bachelor and diploma thesis**
  - Radek Chládek: Odhadování sklonu vozovky multisenzorickou fúzí na palubě vozidla (bak. práce FEL, 2023)
  - Matouš Vondrášek: Odhadování decelerace vozidla fúzí měření z akcelerometru a odometrie (bak. práce FEL, 2023)
  - Vít Fanta: Energeticky efektivní řízení kolejových vozidel (diplomová práce FEL, 2023)
  - Martin Škoudlil: Real-Time schedulability analysis of Rust r2r crate for ROS 2 (diplomová práce CIIRC, plánované odevzdání 2024)
- Conference papers
  - Michal Sojka: Jak na ROS pomocí Nixu. *Presentatace na konferenci LinuxDays’23* (CIIRC ČVUT 2023)
- Journal papers
  - Jaroslav Moravec: Automatické kalibrace systemu s LiDARy a kamerami (v recenzním řízeni, FEL ČVUT, 2023)
  - Oliver Kost et al.: Identification of GNSS Measurement Error: from Time to Elevation Dependency. *IEEE Transactions on Aerospace and Electronic Systems,* 2023 (accepted for publication, UWB FAS)

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-008 (O, Jiri Vokrinek, FEE CTU)

Dynamic multimodal transport optimization – specification of optimized means of transport for dynamic multimodality in transport

A report summarizing a definition of a minimum set of sensors for identifying the state of the environment affecting the choice of means of transport and the potential of using specific means of transport within the entire journey and identification of similarities and differences in the field of micro-logistics, "last-mile" logistics and human mobility, leading to the definition of optimized means of transport.

Due 12/2-25 | CTU FEE 0.5 | CTU FME 0.5 |

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-008

Dynamic multimodal transport optimization – specification of optimized means of transport for dynamic multimodality in transport

- Goals
  - Target use-case: traffic management and transport organization in highly populated areas
  - Optimization of dynamic and permanent multimodal transfer nodes, vehicle fleet composition and positioning, and vehicles parameters limitations and requirements
  - Design of optimization algorithm for number of different types of vehicles and locations
  - Multilevel transport optimization with heterogenous vehicle types and spatio-temporal dynamics
- Activities
  - Identify the principles/quantities influencing the use of different means of transport
  - Definition of the necessary sensory equipment for monitoring these quantities
  - Analysis of available sensors and design of new types of sensors and their generic locations
  - Definition of supported multi-modal use-cases
  - Definition of multi-modal transport optimization problem and first algorithm scatches

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Current State of Deliverables and Fulfillment of Goals

- No binding deliverables (Gfun, R) in 2023
- 6 deliverables O (publications)
- Goals for 2023 in progress, no major delays
  - HW platform prototypes implemented (sensor head)
  - Collection of real time data for performance evaluation started
  - First results from sensor fusion and Lidar data processing (SLAM)
  - Design of software architecture and core algorithms

Added Value of 4-WP01 results

- Advanced Driver Assistant functionality is becoming compulsory part of public sector tenders
- 4-WP01 deliverables provide enabling technology for implementation of base level Advanced Driver Assistance and Colision Avoidance System to meet the minimum tender requirement
- Estimated production of vehicles enabled with advanced systems in 2026 and the following years is 60 units per year

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Assessment of the Contribution of Deliverables

- Advanced localization developed in 4-WP01 by academic partners will be also used in OBU development in 3-WP01 (scaled down version, no Lidar and optical sensors)
- V2X technology developed in 3-WP01 by Herman Electronics partner will be used in 4-WP01 by Skoda Digital partner

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Assessment of the Formal/Administrative Goals of the Work Package

	Skoda Digital	FEE + CIIRC CTU	FAS UWB
Finance	OK	OK	OK
Commercialization	N/A	N/A	N/A
Deliverables	N/A	OK	OK

Content of 4-WP01 Advanced localization and driver assistance systems for trams

4-WP01 – Tools for Integration of Vehicles into Multimodal Systems with Increased Safety (including cyber security) and Subjected to LCA

Coordinator of the WP

Czech Technical University in Prague, prof. Ing. Vladimír Havlena, CSc.

Participants of the WP (4 – WP01 – 007 only)

CTU FEE – doc. Ing. Jiri Novak, Ing. Jan Sobotka, Ing. Jakub Svatoš, Bc. Vojtěch Tecl, Bc. Peter Fučela, Bc. Lukáš Kulhánek, Tomáš Veselý, Alex Olivier Michaud

ŠKODA AUTO a. s. – Ing. Jiří Blecha, Ing. Jaroslav Hrbek, Ing. Adam Šťáva

TÜV Süd – Ing. Dalibor Zeman, Ing. Vladislav Kocián, Ing. Petr Lockenbauer

Main Goal of the 4 – WP01 – 007

Provide a communication technology enabling seamless integration into in-vehicle networks while providing for monitoring with hardware accelerated filtering, PTP support and real-time data manipulation/insertion.

Partial Goals for the Current Period

Detailed specification of result functionality, selection of suitable development tools and their purchase (system on chip based development kit), implementation of monitoring (with HW accelerated filtering) capability.

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Deliverable 4-WP01-007 (Gfunc, Jiri Novak, FEE CTU)

Programmable hardware platform for tests of vehicle communication channels

The hardware platform provides for intrusive and non-intrusive tests of various security aspects of in-vehicle communication. It is equipped with high number of various type (CAN, LIN, Ethernet …) communication interfaces, allowing low-latency monitoring and on-the-fly data manipulation at selected OSI layers (while non-manipulated layers are not influenced). Seamless integration into the vehicle networks will guarantee that normal vehicle functionalities are not affected by test equipment. The platform allows implementing the attacks from the threat catalog R155 as well as from the VW threat catalog. An API providing for particular threats testing is defined and example test cases are implemented.

Due 12/2025 | CTU FEE 0.3 | SkodaAuto 0.6 | TUV 0.1 |

Content of 4-WP01 Advanced localization and driver assistance systems for trams

4-WP01-007 Programmable hardware platform for (non-)intrusive tests of vehicle communication channels

Activities

- detailed specification of result
  - application for whole vehicle monitoring and testing
  - HW accelerated filtering
  - seamless integration (PTP support)
  - real-time data manipulation
  - new data insertion
- selection of suitable tools
  - off the shelf KRIA development kit (system on chip) with two 1Gbps and single 10Gbps interface
  - 100/1000Base-T1 to 100/1000Base-T media converters
- data acquisition (monitoring) implementation
  - DLL implementation in FPGA (including 10Gbps)
  - 1Gbps links data aggregation into 10Gbps port with HW accelerated filtering

Content of 4-WP01 Advanced localization and driver assistance systems for trams

4-WP01-007 Programmable hardware platform for (non-)intrusive tests of vehicle communication channels

Current State of Deliverables and Fulfillment of Goals

In progress & no major delays

- HW as well as SW platforms were selected and purchased (KRIA system on chip, VHDL code for FPGA programming, bare-metal real-time code, Linux GUI for configuration)
- 100/1000Base-T to 100/1000Base-T1 media converters were purchased
- VHDL code implemented for 100/1000Base-T1 network segment communication monitoring
- multiple segments simultaneously monitored communication can be aggregated into single 10GBase-T upstream interface

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Acknowledgment

This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Center II, project # TN02000054 Božek Vehicle Engineering National Center of Competence (BOVENAC).

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Abstracts of publications

Radek Chládek: Odhadování sklonu vozovky multisenzorickou fúzí na palubě vozidla (bak. práce FEL, 2023)

Tato bakalářská práce se zaměřuje na odhad sklonu vozovky na základě multisenzorické fúze na palubě kolejového vozidla. Znalost sklonu vozovky se ukazuje být kritickou informací pro vývoj antikolizních systémů, a to zejména pro odhad brzdné dráhy. Dále se tato znalost může využít při plánování energeticky optimálních rychlostních profilů. Práce shrnuje vybrané související texty (články, knihy). Je zde popsán a navržen matematický model podélného pohybu kolejového vozidla. Tento model je v práci využit pro vygenerování syntetických průběhů relevantních veličin. Dále jsou popsány a implementovány tři konkrétní metody, které tyto průběhy využívají pro odhad sklonu vozovky. Jmenovitě Luenbergerův pozorovatel, rozšířený Kalmanův filtr (EKF) a EKF s průměrováním z více průjezdů stejné trasy. Metody jsou naimplementovány v prostředí Matlab a Simulink a mezi sebou porovnány.

This bachelor thesis focuses on road grade estimation by multisensor fusion onboard a railway vehicle. The knowledge of road grade proves to be critical information for the development of collision avoidance systems, namely for estimation of braking distance. Furthermore, this knowledge can be used for designing energy-optimal speed profiles. The thesis summarizes methods used today (described in articles or books). A mathematical model of the longitudinal motion of a railway vehicle is described and designed here. The model is then used for generating synthetic measurements of relevant variables. Additionally, three specific methods, that are using the above mentioned variables, are described and implemented in the thesis. Namely the Luenberger observer, the extended Kalman Filtr (EKF), and the EKF with averaging from multiple runs over the same route. All of the methods mentioned above are implemented in the Matlab and Simulink environments and compared against each other.

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Abstracts of publications

Matouš Vondrášek: Odhadování decelerace vozidla fúzí měření z akcelerometru a odometrie (bak. práce FEL, 2023)

Tato práce se zabývá odhadem decelerace vozidla. Toho je dosaženo fúzí měření z akcelerometru a odometrie. Měření z odometrie je nejprve zpracováno na rychlost. K potlačení šumu a samotné fúzi následně poslouží komplementární filtr.

This work is focused on estimation of vehicle deceleration. The goal is achieved by accelerometric and odometric data fusion. Odometric data are at first processed in order to extract angular velocity. Noise suppression and fusion itself is done by complementary filter.

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Abstracts of publications

Vít Fanta: Energeticky efektivní řízení kolejových vozidel (diplomová práce FEL ČVUT, 2023)

Cílem této práce je představit problém optimálního řízení vlaku a implementovat open-source softwarový balíček, pomocí něhož je jej možno řešit. Řešením je rychlostní profil, který bere v úvahu trakční limity vlaku, celkový čas cesty a výškový profil tratě a zároveň minimalizuje celkovou vynaloženou energii. Optimální strategie spočívá v přepínání několika jízdních režimů: maximální trakce, držení rychlosti, optimální brzdění, výběh a maximální brzdění. Na ploché trati má optimální strategie podobu maximální trakce – (držení rychlosti) – výběh – maximální brzdění. Na obecné trati může docházet k většímu množství přepnutí kvůli příliš strmým úsekům. Řešení bylo implementováno v jazyce Julia a je dostupné veřejnosti v podobě balíčku na GitHub. I přes to, že je program obecně funkční a příklady výpočtu jsou uvedeny. Některé funkcionality stále chybí (především možnost zahrnout rychlostní omezení). Současné řešení je však možno dále vyvíjet díky jeho open-source povaze.

The goal of this thesis is to present the problem of optimal train control and implement an open-source software package able to solve it. The solution is a speed profile which takes train’s traction capabilities, total journey time and the track gradient into account while minimising the total required energy.

The optimal control strategy is a switching strategy between a small number of modes: Maximum Power, Cruising, Optimal Braking, Coasting and Maximum Braking. On a flat track, the optimal strategy has the form Maximum Power – (Cruising) – Coasting – Maximum Braking. On a general track, more switching can occur due to the steep uphill and steep downhill sections of the track. A solution has been implemented in the Julia programming language and is available to the public in a form of a package accessible on GitHub. The solution is functional and examples of speed profile calculation are shown. Some features are still missing, most notably inclusion of speed limits. Functionality of the implemented solution can be further developed thanks to its open-source nature.

Content of 4-WP01 Advanced localization and driver assistance systems for trams

Abstracts of publications

Oliver Kost, Jindřich Duník, Ondřej Straka, Ondřej Daniel: Identification of GNSS Measurement Error: From Time to Elevation Dependency. *IEEE Transactions on Aerospace and Electronic Systems*, 2023

This paper deals with the identification of the GNSS measurement error properties. For this purpose, an extended version of the measurement difference method, which does not rely on knowledge of the state dynamics, is developed. The method provides elevation-dependent estimates of the pseudorange and pseudorange-rate measurement error properties in the form of both; the autocovariance function and the parametric model including the correlation time constants. The identification method is thoroughly discussed and verified using simulated and real Galileo E5b data and the identified models are utilised in the positioning solution. The identified measurement model improves the positioning accuracy by more than twenty percent.