Rail Localization On-Board unit (LOC-OB) design

WP4 – Design & Development

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101082624

TABLE OF CONTENTS

Table of figures

INTRODUCTION

The CLUG 2.0 project, as a continuation of its predecessor project CLUG (finalized in May 2022), has seen very significant progress on the Localization On-Board (LOC-OB) functional architecture through complementary design focusing on:

- the track selectivity function prototyping,
- the sensors and system data Fault Detection and Exclusion (FDE) algorithms,
- the Confidence Intervals computation for along-track position, speed and acceleration.

These functions are prototyped with algorithmic enhancements in CLUG 2.0, starting to be experimented. Simultaneously, the performance predictions in safety, i.e. the availability of the safe computed CIs within the specified CIs, are improved through refined models and simulation tools.

The mission of the LOC-OB is to continuously produce safe train localization data, along-track position, speed and acceleration with a high safety level (Tolerable Hazard Rate (THR) < 1E-9/h), and other data like the train attitude and 3D kinematics. These localization data are inputs for many train control applications including CTMS, Train Protection Trackside, Train Protection on-board, Passenger Information System, ATO, …

The CLUG 2.0 approach relies on using multi constellation Global Navigation Satellite Systems (GNSS), in dual frequency mode (GPS L1&L5 and Galileo E1&E5), augmented by EGNOS, the European Satellite Base Augmentation System (SBAS); firstly with its Dual Frequency Multi Constellation (DFMC) data stream, and possibly later with a future EGNOS stream designed to increase performance for Railways end-users. These EGNOS streams would be granted by the European Agency for Space Programs (EUSPA) as “EGNOS for Rail” services.

LOC-OB functional architecture

The LOC-OB functional architecture relies on multi-sensor tight-coupling fusion, empowered with integrity algorithms. It consists in merging Galileo and GPS, safely augmented by EGNOS, with other sensors (e.g. IMU and speed sensor) especially required in the rail operational environment where GNSS satellite visibility is discontinuous.

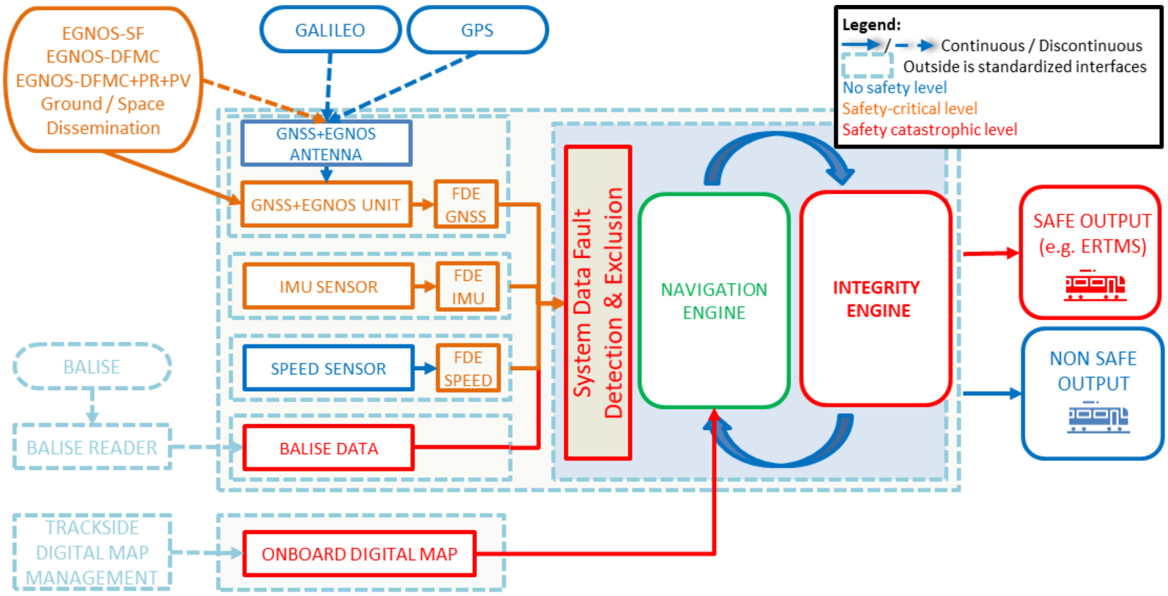

Figure 1 CLUG 2.0 LOC-OB single chain functional architecture

The colour code indicates qualitatively the safety level allocated to each function

Accordingly, the LOC-OB is composed of the following functional blocks:

- Sensors with their associated data FDE:
  - GNSS+EGNOS unit: receives Galileo and GPS signals via roof antenna, safely corrected by EGNOS data, received preferably via the rail network, otherwise via the 2 EGNOS geostationary satellite
  - Inertial Measurement Unit (IMU): provides 3D acceleration and angular rates
  - Speed sensor (e.g. tachometer): provides along track speed raw measurement (not an “odometry system” embedding several independent speed sensors)
  - Balise reader: detects trackside balises, necessary in constrained areas where GNSS is not available for too long (e.g. in long tunnels)
- Navigation and Integrity engine, containing several algorithmic functions:
  - Initialisation,
  - Track selectivity,
  - Along track fusion,
  - System Data Fault Detection and Exclusion (FDE),
  - Integrity confidence intervals computation
- Digital map: data structure containing the 3D multitrack layers enabling the navigation engine to constrain the along-track train kinematics and to determine track selectivity

The role of Data Fault Detection and Exclusion (FDE) is to detect and exclude faulty sensor data. There are two types of FDE, “Sensor FDE” are checking each sensor data individually, and “System FDE” are checking the consistency of sensor data with the estimated train position and speed.

CLUG 2.0 achieved improvements on the LOC-OB overall architecture and on track selectivity, fusion, FDE and confidence interval computation algorithms. In this article, insights are provided on two specific CLUG 2.0 areas of improvement, the dual-chain architecture and on the track selectivity algorithm design.

Dual-chain pragmatic architecture

Achieving a 10-9/h THR with the above functional chain raises several challenges, including comprehensive hazard analyses and certification of complex algorithms at SIL4 development level. A dual-chain architecture is proposed as a pragmatic alternative, where the LOC-OB is completed with a second independent localisation chain, based on a “Shape and heading map matching” algorithm, and a “Combiner” function.

The global THR is split between the GNSS+EGNOS-based chain, at a level compatible with the current SBAS certification level, and the second chain at a lower level. Each chain delivers along track pos./speed/acc. estimates and their associated Confidence Intervals (CIs) to the Combiner function, that computes weighted estimates and the global CI as the union of the CIs from both chains. This function is simple enough to be developed at SIL4 level.

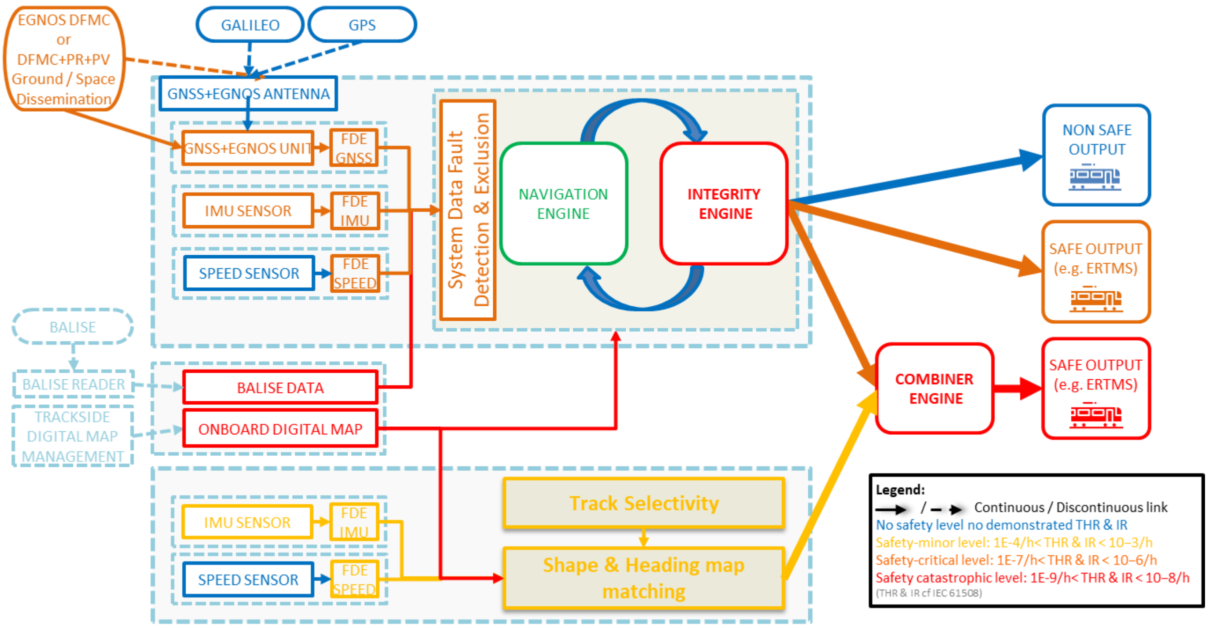

Figure 2 CLUG 2.0 LOC-OB dual chain architecture

The colour code indicates the allocated safety level to each function

Track Selectivity algorithm

The Track Selectivity function design relies on mixing a set of independent shape recognition algorithms running in parallel using measurements provided by non-coupled sensors. Each independent solution provides its own most probable track ID selection with an estimated probability of error. These inputs are merged through a Decision Fusion algorithm selecting the track edge option minimizing the probability of error. The Track Selectivity function is triggered when the train approaches a track switch, and runs until the probability of error matches the required Tolerable Hazard Rate (THR). Combining several algorithms allows to reduce significantly the distance and time delay required for issuing a safe decision for a given THR.

The solution prototyped in CLUG 2.0 relies on a GNSS-based chain and an IMU-based chain. The GNSS-based chain estimates the likelihood of the GNSS carrier phase measurements precise trajectory with respect to the shape of each possible track after the switch, as defined in the Digital Map. The IMU-based chain estimates the likelihood of IMU gyroscope measurements azimuth profile with respect to the azimuth profiles of each possible track after the switch.

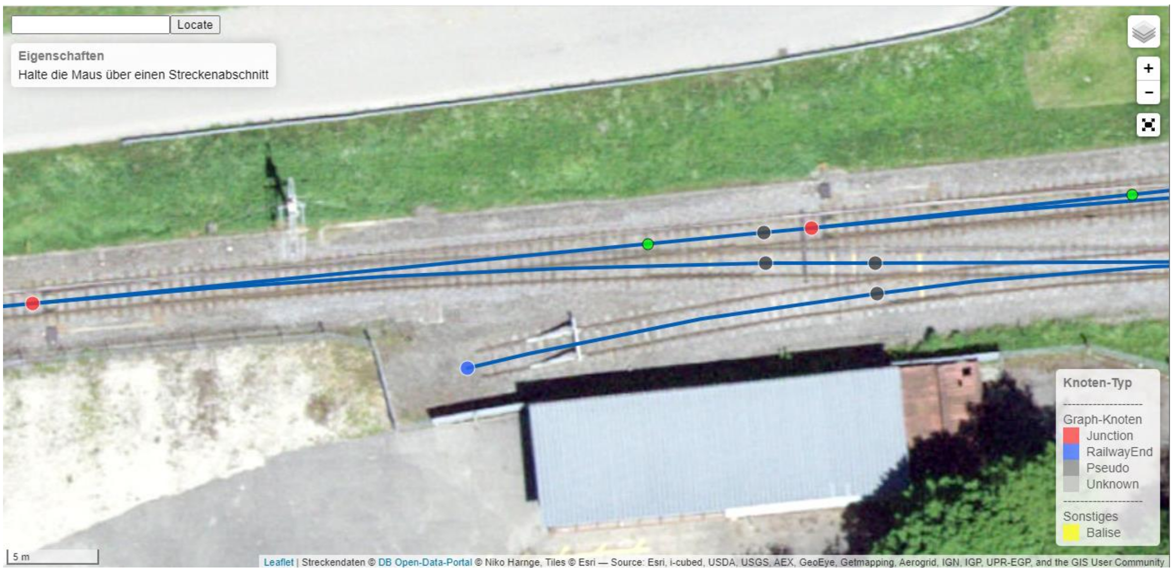

Figure 3 Track selectivity test case (switch ID 6077)

Red dots are the location of track switches, green dots are the location where the decision is sufficiently safe, black dots are Digital Map nodes. The train is running from the left to the right.

Tests conducted with real datasets collected on trains operating in Switzerland demonstrated 100% correct detection and that detection at a 10-10 Hazard Rate requires only 1 to 3 seconds (or a few meters). This Track Selectivity solution is showing very good performance results to reach the high level of integrity required by Rail operations.

LOC-OB prototyping status

The LOC-OB prototype that will be experimented in a later stage of the project now covers almost completely the single chain architecture (only exception being the Initialisation function), and implements an improved design of algorithms. Prototyping and experimentation of the LOC-OB dual-chain architectural option is planned in the frame of the ERJU/R2DATO initiative.

This project has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement No. 101082624