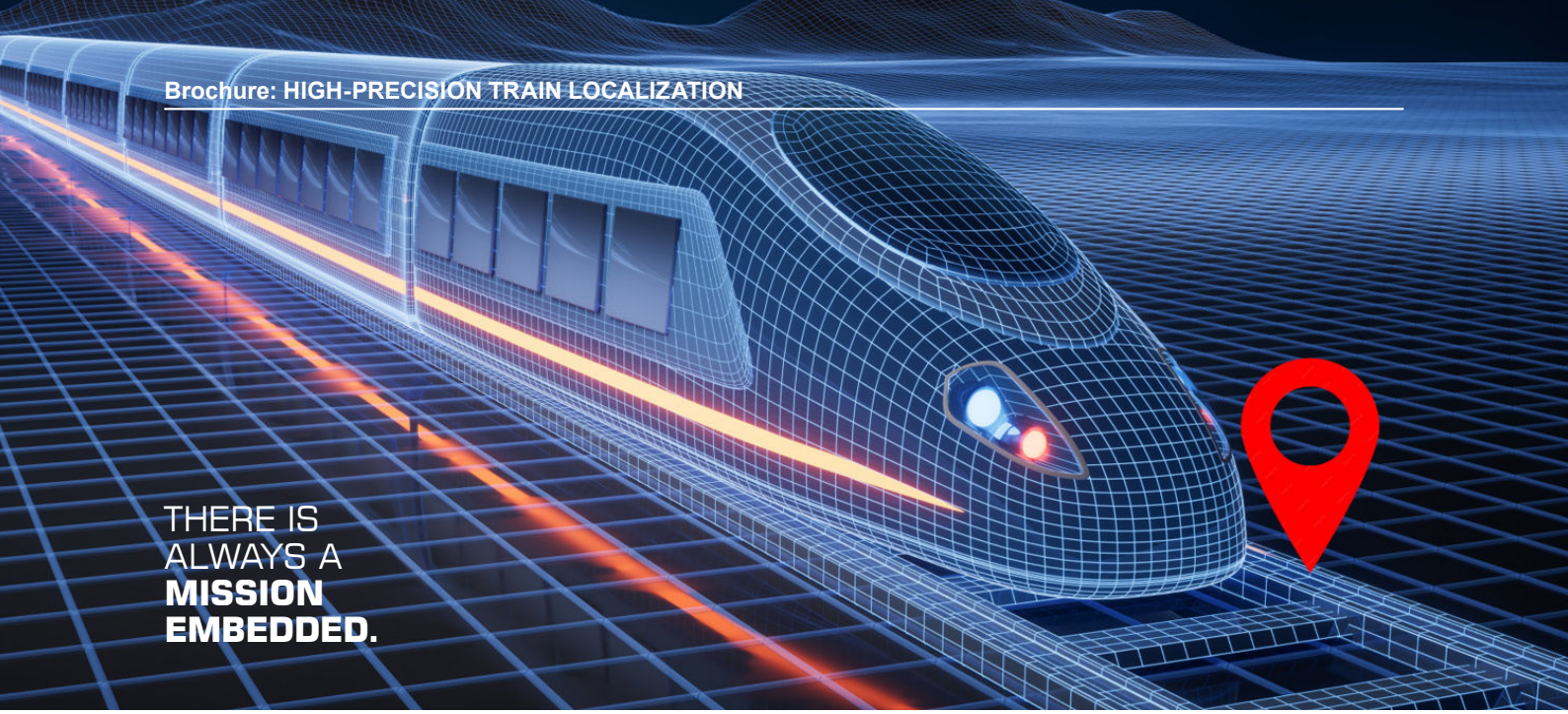

HIGH-PRECISION TRAIN LOCALIZATION

Highly accurate real-time positioning of trains in any environment - using advanced on-board sensors and adaptive sensor fusion technology.

1. Introduction

Within the context of ongoing digitalization, the highly accurate real-time localization of trains has become a key topic for the railway industry.

To effectively manage train traffic in future and maximize the utilization of existing networks, advanced traffic management systems need precise information about the exact positions of all moving trains. Moreover, accurate localization paves the way for a variety of advanced key applications such as Automated Train Operation (ATO), making it a prerequisite for modern railway systems.

Current technical methods for localization use information from various independent sensors placed along the tracks and in the vehicle, measuring the train‘s absolute and relative position.

New on-board localization methods using high precision satellite navigation, advanced sensors and sensor fusion technology provide accurate real-time information on the position and speed of any train - even in challenging environments with limited Global Navigation Satellite System (GNSS).

Through intelligent adaptive sensor fusion these systems are in the position of continuously adjusting and optimizing themselves based on the changing conditions or characteristics of the sensors involved, guaranteeing pinpoint positioning at all times. And this, without the need for costly infrastructure along the tracks.

Current methods of train localization

Standard train localization is based on infrastructure with costly way-side components, supplemented by high-precision satellite navigation systems such as GNSS.

- Localization with track-side sensors

Traditionally, train localization systems depend on track side detection equipment such as axle-counters or track circuits, strategically placed along the railway track. Additionally, the train utilizes wayside reference points such as Balises to communicate its relative position and on-board odometry to measure speed and distance.

These established technologies adhere to stringent railway safety standards and can provide train position information with a precision of a few hundred meters, which is sufficient for providing a train safety system.

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However, the main drawback lies in the high installation and maintenance costs. Given that these infrastructure-side devices are selectively installed in specific blocks at varying distances along the railway track, these systems are not capable of providing continuous and precise localization, which is essential for advanced railroad applications.

Figure 1: Cost-intense trackside detection equipment

For this reason, the need for new positioning methods arises, aiming to locate trains safely, continuously, and accurately on the entire track with as little additional trackside equipment as possible.

- Satellite-based localization

Localization using GNSS (Global Navigation Satellite System) offers the advantage of nearly continuous train tracking without relying on expensive infrastructure. However, these systems face challenges in achieving precise track-accurate train positioning, a crucial requirement for railroad operations. To overcome this limitation, signal correction systems are occasionally employed, offering improved accuracy in certain scenarios.

Nevertheless, the primary obstacle in satellite-based localization arises from signal degradation caused by atmospheric and technical factors, potentially leading to signal loss in densely populated urban areas or tunnels, where GNSS signals may be reflected or obstructed.

Figure 2: Areas potentially lacking GNSS signal

In response to these challenges, industries, such as the automotive sector, have started integrating GNSS data with other sensor information to ensure a more dependable positioning system.

Precise localization with sensor fusion - the key to advanced rail operations

Every sensor system, whether infrastructure-, train-, or satellite-based, comes with its unique strengths and weaknesses. As of now, none of these single solutions adequately addresses today's localization requirements.

This is precisely where innovative new train localization methods with intelligent sensor fusion offer decisive advantages. Through the intelligent fusion of measurement data coming from multiple sensors and technologies, these systems allow continuous track-accurate train positioning in any environment, even in the absence of a satellite signal.

The result is a consistently precise and reliable positioning that significantly enhances efficiency, safety, and track capacity optimization.

Moreover, these novel systems unlock the potential for an enormous spectrum of advanced rail applications, including:

- Advanced Driver Assistance Systems (ADAS)
  Improving the safety, effciency, and the overall effectiveness
- Automated Train Operation (ATO)
  Allowing trains to navigate and operate autonomously
- Intelligent Traffic Management Systems
  Enabling better coordination, scheduling, and optimization of train traffic on the railway network
- Adaptive Train Control Systems
  Allowing for real-time decision-making, enhancing the adaptability and responsiveness of train control systems
- Improved Passenger Information
  Providing accurate and timely data about the train‘s position and status
- Enhanced Safety Systems
  Contributing to collision avoidance, early detection of hazards on the track, improving overall safety
- Predictive Maintenance
  Anticipating and addressing potential issues befo re they lead to service disruptions
- Efficient Energy Management
  Providing valuable information for efficient energy management systems, reducing energy consump tion, and minimizing environmental impact.

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2. Mission Embedded Solution

High-precision on-board localization system with intelligent sensor fusion.

Track-accurate positioning | *Sub-meter precision* | *Unrestricted localization* | *For any railroad system*

The Mission Embedded onboard train localization system is an integrated, end-to-end solution, which provides highly accurate real-time information on the position and surroundings of trains without using additional trackside detection equipment.

The precise localization solution uses GNSS coordinates, inertial measurements, speed sensors, and visual odometry with sensor fusion for complete environmental coverage even in GNSS-denied or limited areas.

Powerful algorithms estimate the train position relative to observed objects and combine this data with IMU readings and GNSS positioning.

In addition, the localized sensor data is synchronized with high-definition digital maps to determine the position. The train locates itself using signature landmarks in the track environment. The software consistently compares the sensor fusion outcomes with the HD map and determines the position based on the currently best available sensor data.

The solution architecture meets the most stringent specifications for precise localization and required safety levels needed for different applications. Moreover, it fulfills high requirements for system availability and reliability, and resilience, using sophisticated security concepts.

Our proven technology has been successfully implemented in rail vehicles worldwide.

The Mission Embedded Train Localization System at a glance

The system provides precise train positioning by fusing data from various sensors, simultaneously validating the data with a digital HD map (Figure 1).

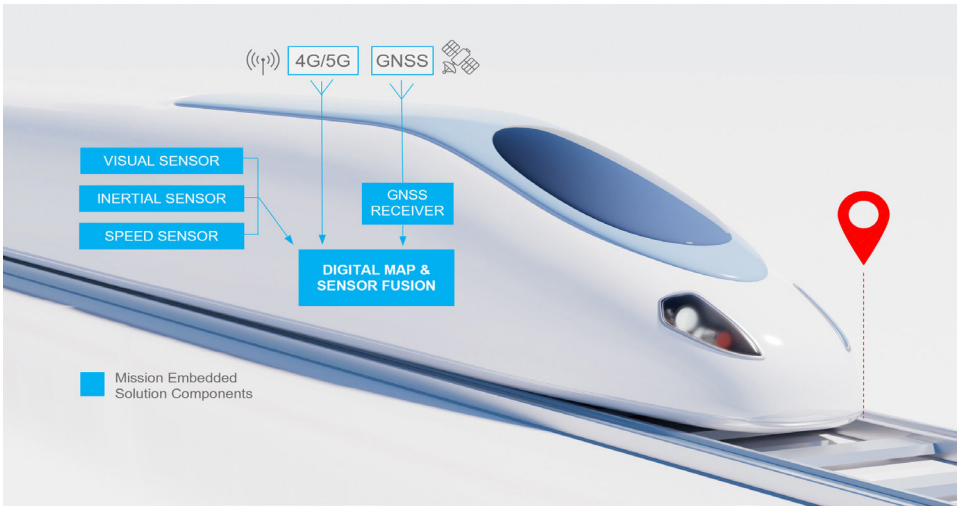

Figure 3: Mission Embedded Train Localization – Solution overview

Positioned with confidence – in any environment

While GNSS data provides absolute positioning in open-sky areas, closed structures and urban environments present a major challenge for navigation.

The Mission Embedded train localization system is a proven solution for precise positioning of trains even in difficult environments such as tunnels.

In the absence of GNSS information, the system enables continuous precise localization of trains by fusing data from visual odometry, IMU, and speed sensors.

Figure 4 illustrates the localization of a train moving through a tunnel, with red representing data obtained

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through visual odometry, ensuring a continuous and precise tracking of the train within the tunnel. In contrast, the system gradually loses GNSS data upon entering the tunnel, as indicated by the yellow and turquoise segments.

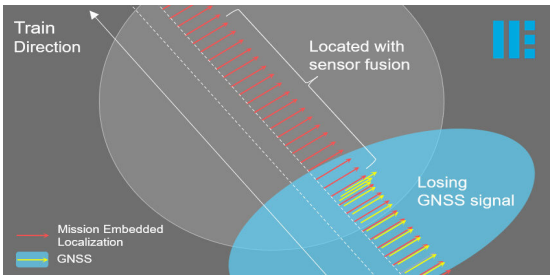

Figure 4: Precise sensor-fusion based train localization in the tunnel, overcoming GNSS signal loss

3. Proven benefits of the Mission Embedded Solution

Mission Embedded's train localization system is a universal and versatile solution, tailorable to the specific needs of operators. It provides an excellent cost-benefit ratio, deriving cost efficiency from its independence on trackside detection equipment and the low sensor costs, allowing numerous rail vehicles to be equipped with the system.

Summary of the benefits

To summarize, the benefits for railway and rail infrastructure operators are multifaceted and can be described by the following key points:

1. **Precise train localization** – even in challenging environments with no GPS
2. **Increased capacity on rail networks** due to optimized train scheduling and advanced traffic management and controls
3. **Real-time information on location**, speed, and trajectory of trains
4. **Support for Autonomous Operations** and Advanced Driver Assistance Systems
5. **Increased safety** due to early recognition and prediction of possible faults
6. **Enhanced passenger experience**, i.e., through real-time train tracking
7. **High cost-effectiveness:** affordable on-board system, reducing the need for trackside equipment
8. **Environmental benefits** thanks to efficient use of resources and improved scheduling

4. About Mission Embedded

Mission Embedded has become a pioneer for intelligent sensor systems in railroad applications. Nearly 1000 sold driver assistance systems for the railroad market prove the expertise and know-how in this field. The application of machine learning and artificial intelligence in various safety critical use cases have led to several pending patents in the relevant field.

Mission Embedded is the partner for your product innovation:

- **100 % Cost Security**

  We guarantee development and series prices right from the start, keeping you in control of your product innovation costs and drastically minimizing your risk. This allows you to focus on your market, while we take care of the technology and implementation.

- **25 Years Investment Protection**

  We offer up to 25 years of long-term support and life-cycle management. To ensure this, we rely on many years of life-cycle experience and intelligent, forward-looking strategies. Even long after market launch, we provide support for maintenance issues, production customizations, and issues in the field.

- **Know-How Advantage from 75+ Experts**

  Real added value is created through a combination of experience and knowledge. We ensure your lead in product innovation with the experience and specific know-how of our highly specialized experts in the core areas of image and sensor processing, sensor and system integration, artificial intelligence, reliability, safety and security, radio and communication, embedded systems, low power systems, and approvals.

- **End-to-End Solution Provider**

  A system from us is more than just a smart combination of hardware, software, and mechanics. We develop solutions that seamlessly integrate into your environment because they are based on an understanding of your needs that goes beyond mere specifications. In addition, we offer an all-around carefree package for your development, and take care of, among other things, supply chain management, just-in-time production, and delivery. So that you get what you need, exactly when you need it – from the concept right down to straightforward support in the field.

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