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Map-matching for train localisation: from the digital map to the map-matching techniques

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Introduction

In the frame of EU-Rail, Flagship Project 2: R2DATO - Rail to Digital automated up to autonomous train operation, WP21 and WP22 work packages are responsible for the Absolute Safe Train Positioning (ASTP). The first of which is centred around the operational needs, and the other is centred in the system architecture, design and RAMS. Main objectives of these work packages are: Identify common high-level user needs and system capabilities of ASTP, Analysis of required system performance for the ASTP system and the definition of a ASTP system architecture and its design.

This article presents the current research in terms of train localisation in fusion with the concept of a digital map. It is organised as follows. The next section presents the state-of-the-art for train localisation, from the digital map to the main categories on the map-matching techniques. Following this, the current state of the research and the future steps are analysed and the last section wraps the article with the conclusions.

Train localisation

Current railway localisation technologies depend greatly on track-side equipment. The most popular used technology for train localisation is odometry in most of the cases complemented with balises, which are detected by the train when it passes by. The balises are numerous on every track and need maintenance work, which drastically increases the cost of this technology for localisation. On top of this, this localisation approach expenses increases with the reach of use.

Therefore, in recent years alternative methods have been studied for train localisation with just onboard sensors. These methods rely on sensors mounted in the train and do not need any track-side equipment. That requires more than just a GNSS (Global Navigation Satellite System) sensor; due its performance, precision and due to the harsh environments and signal outages that can be found in urban or indoor environments.

Railway localisation problem has an inherent property: train motion is constrained to the track, which means that trains can only move mounted on rails. This way, localisation of trains can be considered as a 1-D localisation problem, easing the localisation approach [1]. In this context, estimating the train position on a map of the track is known as map-matching.

Digital Map

Localisation with maps makes a great choice as the maps describe unambiguously train tracks, easing the train localisation and making it an effective choice. On top of that, train localisation with a map requires just onboard sensors and the railway digital map, making it a low-cost alternative to localisation with track-side equipment.

The digital map stores the topology and mileage of the railway network in absolute coordinates. This will need to fulfil the following: accuracy, storage efficiency and usability [2].

Starting from a set of coordinates, the most common digital maps reconstruction are the three shown in **Figure 1**: interpolation, curve and geometric. The interpolation joins the adjacent coordinates with a straight line, the curve is a Unified curve model, such as a spline curve; and the geometric is composed by three main elements: straight lines, curves and clothoids (or easement curves). also called traditional as it is based on the railway traditional design elements

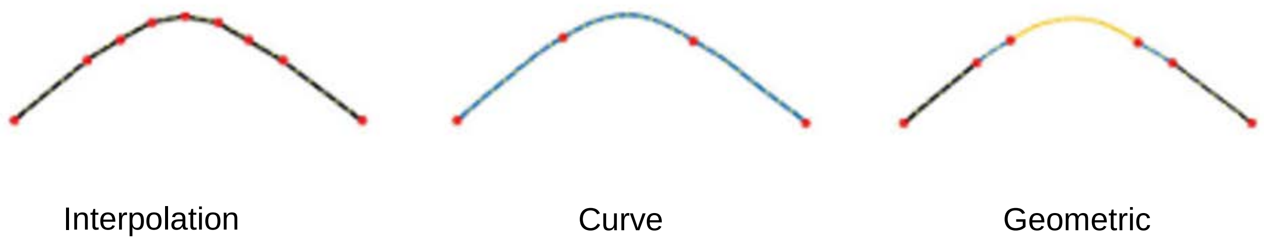

Figure 1: Three main geometries for digital maps. Figure extracted from [3].

Map-matching for train localisation

Even though map-matching for train localisation has been widely studied in the literature, there has not been a classification. The research has been centred on making a classification of the state-of-the-art map-matching algorithms for train localisation.

Three main categories have been identified in the literature for map-matching: geometric, similarity and hypothesis.

1. Geometric

The geometric one considers only geometric information in a naive approach [4]. As the **Figure 2** shows, having a GNSS measurement, the geometric map-matching algorithm will project that measurement onto the digital map to estimate the train position.

Figure 2: Geometric map-matching

2. Similarity

The similarity compares measurement from the sensors with location dependant data. As train localisation can be considered a 1-D problem, matching the measurement of a sensor to the location-dependant data can be used for localisation, as shown in **Figure 3**.

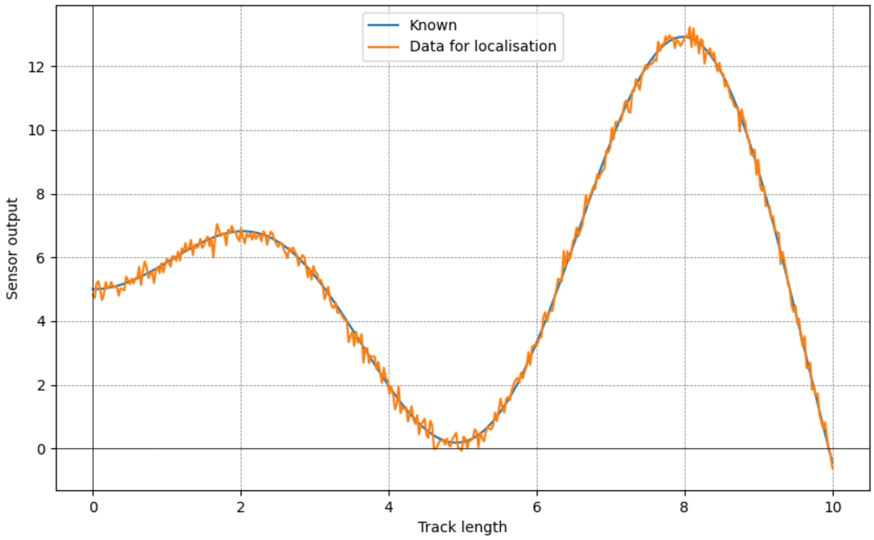

Figure 3: Similarity map-matching

This category is divided in two categories: topological (the known data is the digital map) and feature matching (the location dependant data needs to be recorded for the posterior localisation).

- Topological: The location dependant-data is the digital map.
- Feature matching: The known data needs to be recorded on the track, for the posterior localisation.

3. Hypothesis.

This category exploits nonlinearity by considering positions on tracks as hypothesis. This is divided in two main techniques:

- Particle Filter: Estimates a topological position directly in the track map, as the particles only exist on tracks
- Multi-Hypothesis: Different hypotheses are examined, defined as possible vehicle positions within the rail network

Current work and future work

Our current work is centred around building a digital map using OpenStreetMap (OSM) data, which will serve as a foundational element for enhancing train localization systems. The primary focus of this phase is the creation of a precise digital map of the railway tracks. By extracting and processing OSM data using custom Python scripts, we ensure that the digital map is both accurate and reliable for subsequent localization tasks.

The next step involves integrating this digital map into the train localization system. This will include developing algorithms to match the train's real-time location with the map data, thus enhancing the accuracy and reliability of train positioning.

Conclusions

Absolute safe train positioning is crucial for optimizing train operations, enhancing energy efficiency, and increasing train density while reducing the need for extensive trackside equipment. It also ensures high safety standards, lowers maintenance costs, and improves system availability across various railway applications.

Train localisation problems can benefit from its inherent track-constrained nature via map-matching. This paper presents an in-depth literature review of digital map generations and map-matching algorithms for train localisation. The results of this survey and classification offer valuable insights for practitioners in the field of map-matching for train localisation, paving the way for future research endeavours

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