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Position synchronization for track geometry inspection data via big-data fusion and incremental learning[☆]

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ABSTRACT

Track geometry inspection data is important for managing railway infrastructure integrity and operational safety. In order to use track geometry inspection data, having accurate and reliable position information is a prerequisite. Due to various issues identified in this research, the positions of different track geometry inspections need to be aligned and synchronized to the same location before being used for track degradation modeling and maintenance planning. This is referred to as "position synchronization", a long-standing important research problem in the area of track data analytics. With the aim of advancing the state of the art in research on this subject, we propose a novel approach to more accurately and expediently synchronize track geometry inspection positions via big-data fusion and incremental learning algorithms. Distinguishing it from other relevant studies in the literature, our proposed approach can simultaneously address data exceptions, channel offsets and local position offsets between any two inspections. To solve the Position Synchronization Model (PS-Model), an Incremental Learning Algorithm (IL-Algorithm) is developed to handle the "lack of memory" challenge for the fast computation of massive data. A case study is developed based on a dataset with data size of 18 GB, including 58 inspections between February 2014 and July 2016 over 323 km (200 miles) of tracks belonging to China High Speed Railways. The results show that our proposed model performs robustly against data exceptions via the use of multi-channel information fusion. Also, the position synchronization error using our proposed approach is within 0.15 meters (0.5 feet). Our proposed data-driven, incremental learning algorithm can quickly solve the complex, data-extensive, position synchronization problem, using an average of 0.1 s for processing one additional kilometer of track. In general, the data analysis methodology and algorithm presented in this paper are also suitable to address other relevant position synchronization problems in transportation engineering, especially when the dataset contains multiple channels of sensors and abnormal data outliers.

1. Introduction

Track geometry defects are considered one of the most important factors in operational stability and safety (Esveld, 2001; Higgins and Liu, 2017; Liu et al., 2013; Quiroga and Schnieder, 2012). Track geometry data from track inspection cars is useful for railway maintenance. There are multiple inspection channels corresponding to different types of track geometry, and each channel relates to a

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Table 1
Selected track inspection parameters and methods.

Channel	Type	Sketch Map	Measurement Method	Sensors
1	Gauge	Fig. 1 (1)	Laser ranging	Laser and displacement transducer
2	Longitudinal profile (two sides)	Fig. 1 (4)	Inertial method	Accelerometer and displacement transducer
3	Alignment (two sides)	Fig. 1 (3)		
4	Crosslevel	Fig. 1 (2)	Automatic acceleration compensation	Accelerometer
5	Warp (twist)	–	Difference of crosslevel with a distance of 3 meters	Calculated from crosslevel

specific type of sensor. Taking the GJ-4 track inspection car of the Chinese Ministry of Railways as an example, some track inspection parameters are listed in Table 1 (Ren et al., 2010). The illustrative sketches of different types of track geometry are shown in Fig. 1. Each channel corresponds to a specific type of track geometry.

There have been many studies based on track inspection data, including data measurement (Haigermoser et al., 2015; Weston et al., 2007; Bocciolone et al., 2007; Tsunashima, 2008), track condition evaluation (Tsunashima, 2008; Alfelor et al., 2001; Sadeghi, 2010; Sadeghi and Askarinejad, 2011) and track degradation prediction (Kawaguchi et al., 2005; Bartram et al., 2008; Liu et al., 2010; Xu et al., 2011, 2012; Xu, 2012; Selig et al., 2008). Nearly all the methods and models require high quality inspection data. The use of raw track geometry inspection data from the track geometry car is not always valid due to various data issues, such as measurement errors, abnormal data outliers and positional errors. Among these errors, milepost positional error is one common issue, requiring extensive effort to match and align the positions of the same inspected location from multiple inspections (Xu, 2012; Selig et al., 2008; Qu, 2012; Xu et al., 2013). This effort is not trivial because of the need for estimating and predicting location-specific track geometry deterioration in railroad track maintenance planning. This paper aims to address position synchronization problem from different inspection runs, with a high precision and computational efficiency. The research outcomes can be used for all types of railway systems, particularly high-speed railways, whose track asset management demands a high accuracy in positional information.

In practice, an initial milepost can be manually selected. The subsequent mileage information is obtained according to the rotation angles (by counting the grating encoder impulse number) and the wheel radius (Allotta et al., 2002), as illustrated in Fig. 2a. However, there are inevitable positional errors caused by radial errors of the wheels, faulty encoder output (Qu, 2012), degraded adhesive conditions (Soleimani and Moavenian, 2017, Liu and Bruni, 2015) or track geometry irregularities (Fig. 2d). Due to these factors, the positional error accumulates. To address these issues, the Global Positioning System (GPS) (Specht et al., 2017; Tsunashima, 2008; Allotta et al., 2002), Differential GPS (DGPS) (Allotta et al., 2002; Hanreich et al., 2002) and radio-frequency identification (RFID) (Yang, 2009) are introduced as an absolute reference to control the accumulation of positional errors.

Even though many advanced techniques and devices are used, the positional errors cannot be eliminated and can sometimes reach 100 meters (328 feet). Furthermore, other environmental conditions could lead to abnormal data points. For example, a film of water from rain on the rail-head can cause laser sensor malfunction (Fig. 2c). This kind of abnormal data outlier may influence the performance of the position synchronization method. In Section 2, we review the related work in the literature that addresses this research problem, the respective merit and limitations of each method and the intended contributions of our proposed new approach to the body of knowledge.

2. Related prior work

Positional errors can be classified into three categories, which are (1) absolute position errors (APE); (2) relative position errors (RPE); and (3) channel-inside position offset (CPO). Since our study focuses on position synchronization of data from different runs with multiple measurement channels, our review focuses on RPE and CPO. It should be noted that position synchronization is only focus on RPE and CPO. The track inspection dataset used in this paper has undergone a preliminary processing based on the Key Equipment Identification (KEI) model proposed in Xu et al. (2013).

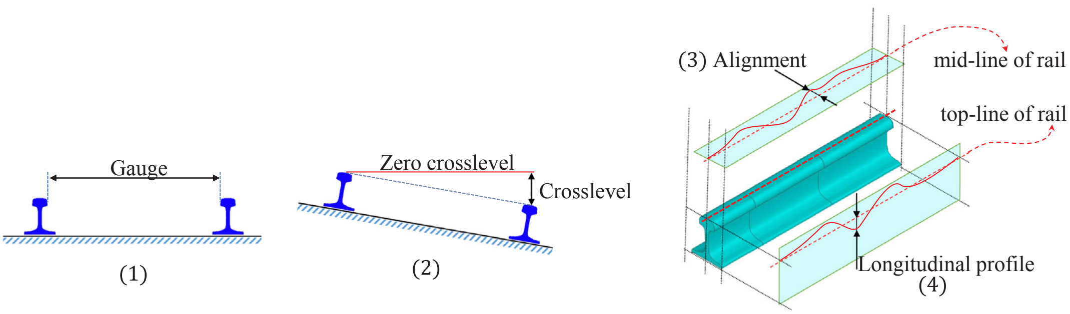

Fig. 1. Schematic diagrams of track gauge, crosslevel, alignment and.