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A cyber-enabled visual inspection system for rail corrugation

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HIGHLIGHTS

- A cyber–physical visual inspection system for rail corrugation is brought forward.
- A new rail localization algorithm is proposed to overcome abnormal illumination.
- A local frequency representation for corrugation images is designed for recognition.

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ABSTRACT

Rail inspection is one of the most important tasks to guarantee the safety of a railway transportation system, and it requires advanced information technologies (e.g. cyber–physical system and cyber–physical–social system) to build intelligent inspection systems. This paper presents a cyber-enabled visual inspection system for rail corrugation, which includes an on-board image acquisition subsystem and a corrugation identification subsystem. In the corrugation identification subsystem, a track image captured by the on-board image acquisition subsystem is first segmented by the rail locating algorithm based on weighted projection profile (briefly as RLWP). And then each column of the segmented rail image is represented by local frequency features and identified as corrugation line or not by a support vector machine (SVM). Lastly, the rail image is judged as corrugation by integrating the recognized corrugation lines. The experiment results show that RLWP is robust and accurate to localize rail region even for uneven or abominable illumination. Moreover, the precision and recall of the proposed corrugation detection system are 98.47% and 96.50%, respectively. They are 25% and 1% higher than those of traditional methods. At the same time, the detection speed is doubly faster than that of the traditional approach. c

1. Introduction

3C (computing, communication and controlling) technologies have been extensively applied in railway industry. A modern railway transportation system is controlled or managed by its cyber-enabled systems using advanced technologies, such as internet of things (IoT), cloud computing, big data, artificial intelligence and social networks. A modern railway transportation system is a complex cyber–physical system (CPS), which constitutes physical systems and their corresponding cyber systems [1–4]. These physical and cyber systems are tightly integrated at all scales and levels to provide a wide range of innovative services and applications. Cyber systems are increasingly embedded in all types of railway physical parts, and make the railway system be more safe, intelligent and energy-efficient.

Railway infrastructures (e.g. rail, bridge and tunnel) are the fundamental physical components of a railway system. High-speed railways and heavy-haul railways require higher quality for the maintenance of various railway infrastructures, so rail inspection becomes one of the most important tasks for the railway industry [5–8]. A railway inspection system can be regarded as a typical cyber-enabled system [2], and it includes four main aspects, i.e. data collection, information processing, decision making and maintenance optimization. As a case study, this paper presents

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a visual inspection system for rail corrugation based on the framework of CPS.

Corrugation refers to a phenomenon of periodical and wave-shaped irregularity, and appears along the longitudinal surface of rail heads. Visual appearance of a typical corrugation is shown in Fig. 3. Corrugation is a typical surface defect for rail heads, and it can cause sharp increase of wheel–rail force [9]. For example, the dynamic load in the section of a rail with heavy corrugation is 2 times more than its static load. This large force would shorten the service life of rails and wheels. In addition, corrugation often makes serious traffic noise, so the rails with heavy corrugation are also known as 'screaming rail'. The noise and vibration produced by corrugation not only make passengers feel uncomfortable but also influence the lives of the residents living along railways. So corrugation detection has attracted more and more attention in recent years [9–11].

Corrugation is traditionally inspected by manual sampling measurement with a special calliper. Obviously, this method is subjective and inefficient. Nowadays, various automatic detection methods have been brought forward, including the chord measurement method and inertial reference method [10,12]. These methods, which are mostly based on mechanical and physical mechanisms, are efficient to measure the physical characteristics of corrugation, such as wave length and depth. They, however, are not efficient enough for routine inspection. This paper puts forward an efficient visual inspection system for rail corrugation (VIRC) based on the principle of cyber–physical system. VIRC first localizes the exact rail position from an original track image. Then it extracts the frequency feature vector for each column of the rail image, and judges whether the column is corrugation line or not based on SVM. Lastly, VIRC makes a final decision about whether corrugation exists or not in the input image based on the judgement results of all corrugation lines. To summarize, the main contribution of this paper includes the following three aspects:

1. We propose a new rail locating algorithm, named Rail localization based on Weighted projection Profile (RLWP), which can effectively overcome the effect of abnormal illumination and accurately locate the position of rails.
2. We bring forward a local frequency representation for corrugation images. This representation achieves better classification performance than the traditional global Gabor features [13]. Furthermore, its computational efficiency is higher than that of Gabor features.
3. We design an actual cyber-enabled corrugation inspection system, which meets the demand of track inspection task and is actually tested in some railway networks in China.

2. Related work

Generally speaking, a modern railway transportation system shows dynamic, open, interactive and autonomic features, and it is a representative of cyber–physical–social system, as shown in Fig. 1(a). It comprises the three spaces, i.e., physical space, cyber space and social space. Physical space includes trains, railway infrastructure (such as rail, bridges and tunnels), other facilities and environmental objects. Cyber space comprises physical sensor networks, social networks, train control system, transportation management information system and so on. Social space involves transportation participants (passengers, drivers, pedestrians and others), culture and management.

- **Physical space** A railway transportation system comprises a large number of physical components, roughly including train, infrastructure and environment. The status of these components determines the safety, efficiency and quality of the railway system, so these components should be precisely monitored and properly operated according to their real-time status. Usually, many kinds of sensors are involved in physical space, including but not limited to the on-board sensor networks, sensors deployed in infrastructure, environmental sensors, and the detectors that are used to capture information from passengers and other transportation participants. For example, in a modern train, diverse sensors are mounted to acquire a series of key parameters, such as the bearing temperature, air brake pressure, power-supply voltage and bogie condition. These parameters are used to determine the condition of the train.
- **Cyber space** Cyber-enabled systems are deeply intertwined and interacted with the physical space. Firstly, The heterogeneous and huge data coming from different sensors and sources needs to be process properly before it can be further exploited by applications. The data is featured with large variety and big volume. The data may locate in different places, including headquarters, divisions and local offices. Nowadays, the data accompanied with information infrastructure (e.g. cloud and big data platform) constitutes the basis of the cyber space. Further, a modern railway system brings together advanced information technologies such as computing, communications and intelligent control to address various aspects of railway systems, for example train control and dispatching, infrastructure inspection, and customer service.
- **Social space** With the development of mobile networks and social network applications, it is easier to share and collect useful information by social networks than ever before. Consequently, social space is emerging as an important aspect of a modern railway transportation system. Basically, railway departments integrate and publish transportation information from multiple cyber-enabled systems effectively. The public acquire these information according to their demands, and make decisions about their travel behaviours, such as travel plans and modes of transportation. Moreover, the public may share the experience and comments about their railway travel by social networks. Further, railway management departments can use the social space to capture social emergency events, environmental status, policy feedback, and service quality. The social space can help railway industry to improve its service level. We have to note that the implementation of such social space should leverage the advanced information and communication technologies, such as mobile internet, big data and artificial intelligence.

Railway inspection is one of the most important task of railway operation to guarantee the safety of railway networks [7]. Traditionally, this task was manually carried out by inspectors with simple tools. Nowadays, rail inspection heavily relies on advanced information technologies. Railway inspection systems are eventually evolved to cyber-enabled systems [8,2], and Fig. 1(b) illustrates the cyber–physical architecture of railway inspection. Generally, a cyber-enabled rail inspection system includes four aspects, i.e. data collection, information processing, decision making and maintenance optimization. However, how to effectively recognize rail defects and to identify potential dangers remains a major challenge for this paradigm.

Corrugation is a type of hazardous rail defect and corrugation inspection has been attracted much attention for railway maintenance [9]. Traditionally, corrugation is inspected by manual sampling measurement with a special calliper. In order to improve the efficiency of manual inspection, various automatic detection methods have been brought forward. These methods can be roughly divided into three categories: chord measurement method, inertial reference method and machine vision method [10,12]. The basic idea of chord measurement is to measure the vertical distance from a middle point to the string that links two highest points on a rail.