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Review On Feasibility of Using Satellite Imaging for Risk Management of Derailment Related Turnout Component Failures

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Abstract. One of the emerging significant advances in engineering, satellite imaging (SI) is becoming very common in any kind of civil engineering projects e.g., bridge, canal, dam, earthworks, power plant, water works etc., to provide an accurate, economical and expeditious means of acquiring a rapid assessment. Satellite imaging services in general utilise combinations of high quality satellite imagery, image processing and interpretation to obtain specific required information, e.g. surface movement analysis. To extract, manipulate and provide such a precise knowledge, several systems, including geographic information systems (GIS) and global positioning system (GPS), are generally used for orthorectification. Although such systems are useful for mitigating risk from projects, their productiveness is arguable and operational risk after application is open to discussion. As the applicability of any novel application to the railway industry is often measured in terms of whether or not it has gained in-depth knowledge and to what degree, as a result of errors during its operation, this novel application generates risk in ongoing projects. This study reviews what can be achievable for risk management of railway turnouts thorough satellite imaging. The methodology is established on the basis of other published articles in this area and the results of applications to understand how applicable such imagining process is on railway turnouts, and how sub-systems in turnouts can be effectively traced/operated with less risk than at present. As a result of this review study, it is aimed that the railway sector better understands risk mitigation in particular applications.

1. Introduction

Satellite imaging (SI) is a constant GIS-based monitoring process by which images, which are often necessary to make an engineering decision on local or global events, are obtained from satellites. As a result of advances in satellite engineering, and an intensive demand for better understanding or observation, satellite imaging has been a must in particular geographically-aimed projects and is expected to be implemented into a variety of even conservative engineering projects in the near future [1]. Therefore, the increasing availability of geospatial-data accessibility and decreasing cost of geospatial technologies might make high-resolution imagery analysis a viable research tool for railway operations, which is one of such engineering projects.

Applications based on SI, in combination with different systems, e.g. communication systems, have been identified to contribute to efficiency, safety and system capacity of operations in different kinds of the other transportation, such as road and sea [2] [3] [4] [5]. On the other hand, studies on utilising satellite technology are quite rare and the technology itself is relatively new to the railway industry and researchers [6]. The design of Rail-Track Geometric Systems has been analysed through satellite measurements [7] and decision support system based on GIS and satellite remote sensing analysis after any earthquake explored to learn whether emergency transportation routes for railways were identified and evaluated [8]. An efficient algorithm for railway track detection has also been developed from low quality images [9].

There has, however, been no study on satellite imaging specifically for railway turnout systems. This study will review and discuss not only whether SI technology is feasible for railway turnouts, but also what problems or failures might be detected

2. Satellite imaging

Part of the raster data types, imagery has been an important visual aid to managing engineering projects and serviced as a source of derivative information for making decision for the last five decades. The first satellite serving as an imaging and scanning space device, Explorer 6, was launched by NASA to understand mainly geomagnetism and radio propagation as well as the Earth's weather patterns [10]. This was followed by Luna 3 to reveal the characteristics of the moon's surface. The current technology is remarkably higher, considering their highly detailed images, than before, and operated by governments and businesses under licenses around the world [11].

2.1. Remote Sensing

In engendering application, remote sensing (RS) often addresses all activities of recording, observing and perceiving of objects or events at far away (remote) places. That is, the sensors of sources, satellites, do not have direct contact with the objects or events being observed.

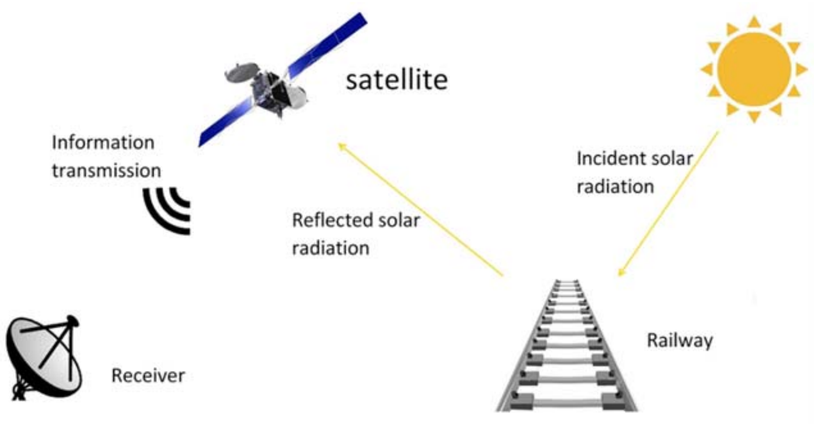

Figure 1. Remote sensing (RS) for railway systems

Figure 1 shows the data required for a carrier to travel from a railway system to satellite sensors through an intervening medium. Solar radiation might be a suitable information carrier for railway systems in remote sensing. The optical sensors of a satellite detect solar radiation scattered or reflected from railway systems. Images resembling photographs taken by a camera high up in space are often formed and then received on Earth through special targeted dishes.

2.2. Image Processing and Analysis

A large number of image processing and analysis techniques/algorithms have so far been developed to help for exploiting as much information as possible from remote sensing image (RSI) and interpreting

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The process begins with image restoration, which is a stage to covert a degraded image, such as images with noise, blurred motion and poor lens focusing, into a defect-free image [12]. The process of dividing an image into separate regions or sub groups is known as segmentation, which is used to reveal meaningful information of an image. This is the phase for the investigation of discontinuities and similarities in the image. Lastly, labels are assigned to objects on the basis of defined descriptors in the recognition phase.

2.3. RS on Railway Turnout Systems

There seems to not be many algorithms conducted to investigate particular parts of railway industry. Figure 2 [9] shows how to detect railway turnout systems through RS. The first two steps are called as pre-processing. This is one of the most significant step in the processing of digital images as the quality of input / acquired image taken by satellites is quite low for such small areas as turnouts. The steps 3 to 6 composes edge detection section in the whole progress. The sharpened image in the previous step is processed for the detection of the track, detecting railway curved and strength track. In order to do this, many algorithms exist in the literature [13] [14] [15] [16] . This process is done for tracking and labelling as railway turnouts are of at least two lines. The step 7 is called as morphological analysis often consisting of two stages, namely; apply erosion to image and apply dilation to output of erosion, both which contribute to filling lines in the image. The last step might be called as marking, which processes the resultant image for contrast and histogram equalization. This allows for recognition of the components of turnouts.

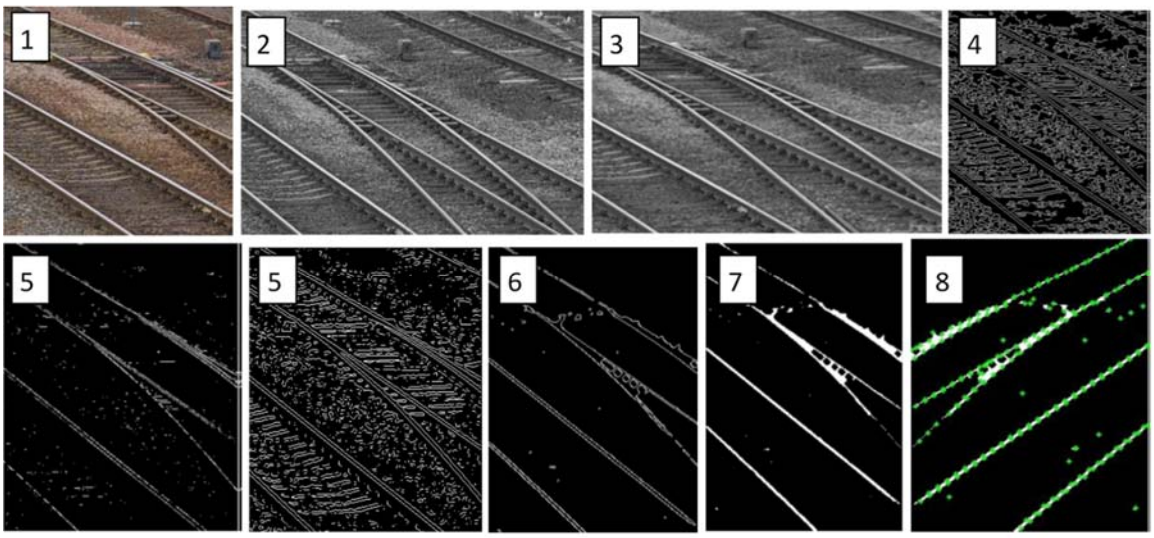

Figure 2 The progress of a proposed algorithm for a railway turnout detection using satellite imagery

3. Derailment based Risk Elements of Railway Turnouts

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Railway turnouts are important mechanical installations for railway operation, transferring a rolling stock from one line to another. They require a variety of engineering works, including earthworks, mechanical-based works, electrification, signalling, optimisation and management. Considering all these engineering works have to harmonise with each other to ensure smooth railway turnout operation, risk on railway turnouts is at high level. To better handle those, Dindar et al. [17] propose a classification, shown in Figure 2, for reducing derailment risk at railway turnouts. This study follows this classification to review what elements are suitable to RS.

Thus, six categories, namely, component failures, operational failures, interaction failures, human factors, environment factors and loading faults, are presented. However, the research is limited to component failures of railway turnout infrastructure.

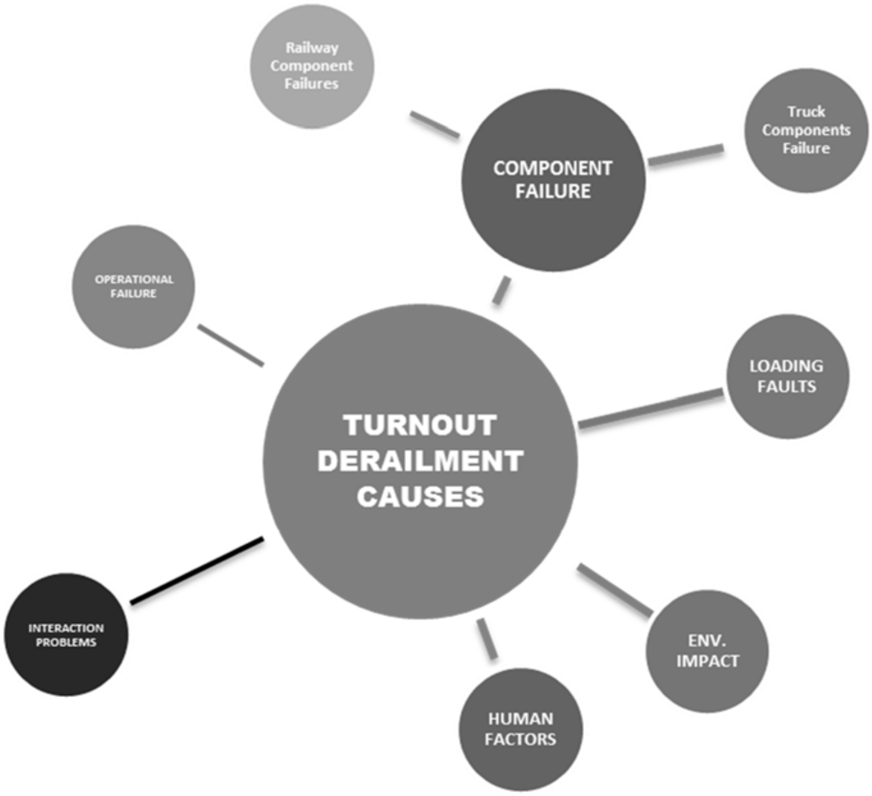

Figure 3 Representation of proposed framework for categorisation [13]

Component failures comprise either railway component failures or truck component failures. Turnout components can vary to some degree as the systems are very vulnerable. Moreover, it should be stressed that this type of failure accounts for the majority of derailment causes at railway turnouts [18]. Failure rates of all components, from subgrade to superstructure, are subject to various variables, including the quality of maintenance, traffic density, climate conditions, material variant in the system, type of line, e.g. freight, passenger, etc [19].

In terms of type of component failures causing derailment, there appear to exist a number of different causes and characteristics. Figure 3 shows a number of defects often seen at railway turnouts and likely to give rise to derailments.

As shown in Figure 3a, transverse crack on the crossing nose occurs in the front area of the crossing nose, and appears as one explicit crack. Possible outcomes are inadequate control of wheel profiles, wheel flange not matching together with design of wheel transfer zone or high vertical impact loading stress. Spalling of stock rail, causing high contact stresses, incorrect profile of wheel flange as well as interaction problems are visible as very small marks on the tread (see Figure 3b). Another phenomenon resulting in derailment at railway turnout systems is shelling, which is a progressive fracture at or near the surface of the rail head, as seen in Figure 3c. It results in cracks due to rolling contact fatigue (RCF) and high dynamic forces. As seen in Figure 3d, squats are dark spots, containing cracks with a circular arc or V-shape, on the rail. These often occur, leading to high contact stress and wheel slip. Lipping, appearing as a plastically deformed lip, is often seen on the surface of the switch/stock rail and wing rail/crossing nose, and requires visual inspection (see Figure 4e). It generally causes non-optimal wheel rail contact and incorrect profile of wheel flange. Head checks (see Figure 4f) are also formed as a result of RCF defect. This can be detected visually as small parallel cracks occurring at the gauge corner. Head checks cause poor contact band conditions. Abrasive wear, as illustrated in Figure 4g, is characterized by excessive wear of the outside rail in turnouts with small radii. The outcomes of this defect include high tensile forces and diverging route. Plastic deformation of wing rail, as shown in Figure 4h, is located in wing rails in the zone of the wheel transfer, and appears as a depression in the running surface and metal flow, resulting in the formation of burr on the inner side of the wing rail. This results in inadequate control of wheel profile, high stress by dynamic forces or wheel flange not matching together with the design of the wheel transfer zone. As seen in Figure 4i, a transverse crack on the crossing bottom leads mainly to casting porosities, poor support conditions or high dynamic forces. It is characterised by a bottom-top crack in the rear zone of the crossing. Large variation of track position in turnout panels, as shown in Figure 4j, is characterized by various visual irregularities in track position. This leads mainly to uneven stiffness in the construction and dynamic forces on the whole structure. As shown in Figure 4k, cracked or broken concrete bearers mainly occur in the near contact area with the chair and are characterised by a defect in the concrete bearer, which has a potential to result in the inability of the bearer to support the track system. This causes foreign obstacles in screw holes when tightening, poor installation, high dynamic loads and inconsistent support conditions.

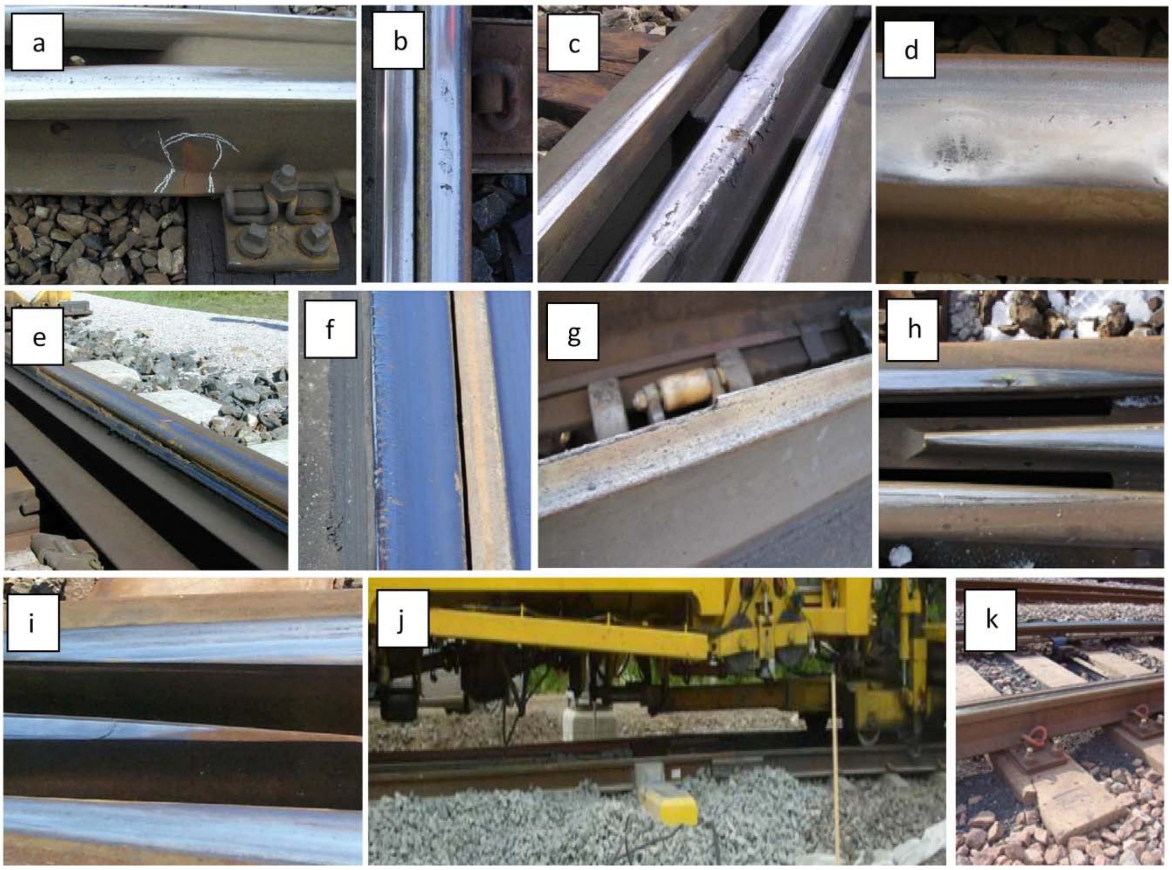

Figure 4 Component defects of railway turnouts

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4. Discussion

As truck component failure is not counted as infrastructure, those are out of the interest of this study. Moreover, the type of component failure is often undetected or rarely detected, even in inspections. The application of RS to this type of failure seems to be unrealistic. However, for various types of track components, including rail, trackbed, etc., its use might be feasible.

It is important to understand to what degree the defects listed and argued in the previous section can be detected through remote sensing through satellite. As there are only around 10 relevant studies at this point, it is almost impossible to say that such a technology could or could not help railway operation. However, it is known through engineering applications other than railway industry that RSIs are often used as the basis of day-to-day investigations of these engineering systems. Investigation of component defects at turnouts is usually done at weekly or monthly intervals, depending on maintenance policy and the conditions of line and turnout components. On the other hand, the question of whether such a detection technique is suitable to adopt for railway maintenance relies on the sensitivity of detection, which is related to the high resolution satellite images, size of the detection area and algorithms. Although the resolution of RSIs is increasing with new satellite launches, it can be argued that the outcomes are currently not satisfactory for such a small detection.

However, as stressed in Section 2, the detection of railway line, switches and crossings has been achieved through RSIs. In this regard, it could be suggested that large variations of track position in turnout panels (see Figure 4 j) could be detected through such a technique. This might help to reduce the maintenance cost of light traffic lines in rural areas where these kinds of failures are generally seen. It is known that trackbed-related problems which often result from natural impact can easily be detected. However, poor maintenance regime and long intervals make the detection difficult. RSIs are considered to be feasible for this detection using today`s optic and software engineering.

On the other hand, failures of movable parts of turnouts, such as switch blades, give rise to derailment, especially in heavy traffic. Whether a pair of switch blades is well-positioned through RSIs by satellite could be considered. However, the appropriate algorithm needs be used for every moment of operation. This seems to not be feasible for many reasons, such as changes in weather conditions and positioning of satellites, which means failure observations through RSIs by satellites offer a limited contribution to inspection.

5. Conclusion

Considering the current capability of satellite-based RSIs, the possibility of crack detection on track and sleepers is almost impossible. However, visible large scale failures are likely to be detected. For instance, washout, the sudden erosion of a trackbed by a gush of water, occurs in areas with rainy climate. The impact of this failure type might be detected through RSIs. With the help of the increasing quality of sensors in the satellites, it could be expected that failures less easily detectable than earthworks, such as track irregularities like buckling, can be adapted to inspection strategies through this kind of technology.

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