



USING OF SATELLITE DATA FOR RAILWAY INFRASTRUCTURE MONITORING

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Abstract – Structural stability and operational safety of transport structures, including railways and bridges, can be ensured by continuous monitoring of these structures and their surrounding environment. Several satellite remote sensing technologies have proven to be suitable for this task in the last few decades. This study conducted a review of literature on using satellite data for railway infrastructure monitoring, with respect to the application/use-case, and used satellite technology.

Keywords – earth observation, satellite, monitoring, railway infrastructure.

1. INTRODUCTION

The use of Earth Observation (EO) for railways has been increasing in recent decades. In this context, EO data are normally those acquired from remote sensing platforms, such as Global Navigation Satellite Systems (GNSS) [1]. Data from EO satellites is transforming rail operations by providing insightful analysis, identifying problems before they escalate and optimising operational efficiency. Advanced satellite sensors delivering detailed EO data, combined with AI, enable rail network management to become more efficient, effective, and safer.

This paper provides review of literature on using satellite data for railway infrastructure monitoring. Review of literature with respect to the application/use-case, as well as a review with respect to used satellite technology is given.

2. USING OF EARTH OBSERVATION DATA FOR RAILWAY INFRASTRUCTURE MONITORING

The published papers can be grouped with respect

to use-case for railway operators. EO was used for monitoring of rail track deformations, vegetation and water level around the rail track, ground deformation, railway transition zones, and railway bridges.

Increased traffic, combined with higher speeds and axle loads, impacts the rail track geometry. Therefore, early detection, identification, and analysis of potential deformations along rail track is of crucial importance [2]. Chang et al. [2] presented a methodology for fine-tuning satellite radar interferometry to railway infrastructure for near-real-time monitoring of changes in the rail track geometry. The same technology was used for monitoring rail track deformations over the entire railway network of the Netherlands [3]. Specht et al. [4] presented a complex method for the evaluation of the GNSS measurements for the purpose of rail track geometry assessment. Chang et al. [5] used categorized sub-structures of the improved Sentinel-1 derived Persistent Scatterers (PS) to identify deforming railway structures. Persistent Scatterer Interferometric Synthetic Aperture Radar (PSInSAR) technique with high-resolution TerraSAR-X satellite images was also

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used to measure and analyse deformation at the operating rail track in South Korea [6].

The vegetation on the railway network must be efficiently controlled to ensure the safety and regularity of train traffic, as well as the good condition of the railway infrastructure. Satellite data can be used to get a detailed inventory of railroad areas, by extracting of rail tracks, separating of different states of plant succession, or differentiating between surface types with varying degrees of impermeability, at appropriate scales for urban ecological monitoring and assessment [7]. Kučera and Dobesova [8] presented a method using satellite image data to identify the degree of threat to railway infrastructure in Czech Republic from falling trees according to three parameters: the height of tree stands, species composition, and vegetation health. Satellite image data and machine learning algorithm were used for supervised classification of vegetation on the French railway network [9].

The level of water near a railway track is a major factor affecting the safety of train passage and cargo. Arroyo-Mora et al. [10] proved that comprehensive information at multiple scales consisting of Unmanned Aerial System (UAS) data and satellite image data can be used to detect and monitor fine scale changes of water area and level around railway tracks.

The condition of the railway substructure is critical for the longevity of rail tracks. In recent decades, various non-contact monitoring and analysis systems for ground deformation have been developed [11]. PSInSAR patented by the “Politecnico di Milano”, an efficient tool for high precision monitoring of deformation of the Earth’s surface based on the use of a time series of satellite radar images, was used for the identification of unstable areas affected by surface movements [12]. Tan et al. [11] applied satellite radar interferometry to measure subgrade deformation in the test site along the Qinghai-Tibet railway in permafrost region. Bernhard et al. [13] estimated surface deformations along railway tracks in Northern Switzerland by conducting a Persistent Scatterer Interferometry (PSI) analysis utilizing time series of TerraSAR-X satellite observations. Satellite Synthetic Aperture Radar (SAR) data processing results for surface displacements for the railway line in Bulgaria proved to be reliable when compared and analysed with results from GNSS networks [14].

Transition zones in railway tracks are locations with considerable changes in the rail-supporting structure. Without timely maintenance, the differential settlement may lead to the damage of track components [15]. Interferometric Synthetic Aperture Radar (InSAR) technology is also widely used in this area, whose results show a good correlation with measurements obtained using a measuring coach and

a Digital Image Correlation (DIC) device [15].

Many of the railway bridges built in the second half of previous century need to be rebuilt due to increased traffic loads, accumulated deterioration, and more stringent bridge design codes. Extreme weather conditions, such as temperature change, flooding, and wind loading, can also affect the structural health of railway bridges [16]. Zhu et al. [17] demonstrated the performance of the continuous monitoring of the foundation displacement in long-span bridges with GNSS technology. InSAR technology was also applied to railway bridges. It was used for 3D visualization and early warning of unexpected bridge displacements [18]. The same authors introduced the concept of displacement thermal sensitivity.

3. USED SATELLITE DATA, SATELLITES AND PROCESSING METHODS

The most broadly used satellite data are SAR data [2, 3, 5, 6, 11-15, 18]. SAR systems are able to measure the sensor to target distance by recording the time elapsed between the emission of the electromagnetic wave from the satellite towards the Earth’s surface and the reception of the signal that is back-scattered by the ground itself [12].

The measurement of displacements on ground structures down to the millimetre level requires the processing of several radar images taken at different times using advanced techniques, such as interferometric SAR (InSAR) [2, 3, 5, 6, 11-15, 18].

The PSInSAR technique aims to detect radar targets on the Earth’s surface identified by the satellite in that area that are characterised by a stable temporal electromagnetic response – Permanent Scatterers (PS) – which generally correspond to ground elements such as manufactured structures (including railway tracks) [6, 12].

TerraSAR-X radar satellites were most often used to obtain SAR data [2, 6, 13, 15], followed by RADARSAT-1 and RADARSAT-2 radar satellites [3, 12, 18], Sentinel-1 satellites [5, 14], and Envisat/ASAR satellites [11].

The methods used to process SAR data vary from probabilistic method for InSAR time-series postprocessing [3], to method for PS geolocation improvement aided by Light Detection and Ranging (LiDAR) data [5], and method for deriving optimal data by analysing algorithms that account for the unique characteristics of railways traversing urban, farmland, and mountainous areas [6].

GNSS data are used not only for navigation in railways, but also for monitoring of railway infrastructure. Specht et al. [4] used GPS and GLONASS satellite data. They performed measurements using receivers installed on a moving rail vehicle. Zhu et al. [17] used GPS and BeiDou satellite data for monitoring displacement of railway

cable bridges. The GNSS data were corrected by establishing non-linear mapping between the GNSS data and precise levelling data by back propagation neural network to improve the observation accuracy.

In the remaining studies, related to monitoring of vegetation and water level around the rail track, researchers used data from the QuickBird satellite [7], Sentinel-2 and Landsat 7 satellites [8], Pleiades satellites [9], and PlanetScope Dove satellites [10].

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