The Development of BIM-AR Structure Health Monitoring System for High-Speed Railway Infrastructure Management

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1. Introduction

Applying Structure Health Monitoring (SHM) approaches to the life cycle management of the railway infrastructure facilitates decision-makers to identify potential structural problems at early stages, further guaranteeing rapid reactions against problems, saving extra maintenance cost and increasing operational safety. In the current practice of High-Speed Railway (HSR) projects, there is a lack of generalized management procedures to realize SHM data transparency to be considered with construction/maintenance schedule and budget. Furthermore, lacking intuitive visualization for field inspectors, based on the structural analysis results, also hinder the accuracy of inspectors' judgments for further infrastructure interventions. Hence, Building Information Modelling (BIM) is introduced and expected to facilitate the collection of SHM information and further structural diagnosis results. A cloud-based BIM system is necessary for modelling the infrastructure, collecting sensory information, visualizing structure health conditions and supporting maintenance/operation decisions. On the other hand, Augmented Reality (AR) display can be an extension of the BIM system to be used at the field, for positioning and overlapping the SHM information with the real structures. They can be useful in showing the significant damages at the right place to enhance inspection performance with better validation quality.

2. Approach/Methodology

In this project, a BIM-AR integrated system for SHM of infrastructure life cycle management is developed. The essential functions can be seen in Fig. 1 and the web-based platform of the system is shown in Fig. 2.

Timeline (schedule)

Gantt chart is used as a Timeline in this system, which represents the construction/inspection/maintenance sequence of the infrastructure. It consists of all defined tasks with planned or actual time duration (time bar) for their corresponding activities. Once the time bar is clicked, the viewer will highlight the components corresponding to the selected tasks as Fig. 3.

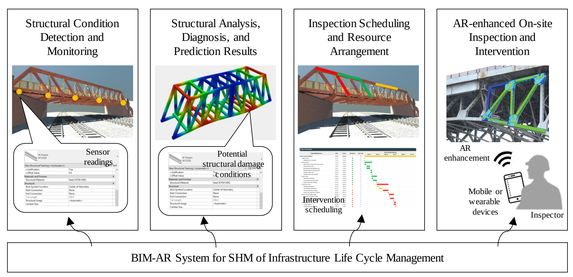


Fig. 1: The essential functionalities of the BIM-AR SHM system for HSR infrastructure

Structural health monitoring

To determine the potential structural issues for structural engineers, BIM-AR also provides further simulation (Fig. 4a) to continuously monitor different sensor readings on the infrastructure when exerting dynamic loading. It helps the engineers to inspect the sensor readings for identifying any abnormal situation. Once any reading of strain gauge is above the pre-set event trigger level (120με), the accelerator sensor readings starting from 1 minute before the event until 1 minute after the event and the transferred spectrum will be reported to the BIM-AR system. Based on the EN 1990 - Basis of structural design, the event will be highlighted as Fig. 4b once the accelerator reading is over 0.7 m/s2 or the fundamental frequency is less than 5 Hz.

AR inspection

AR display is adapted to superimpose structural conditions with the actual structure, to enhance the perception ability of field inspectors. It is designed to help conduct a more accurate inspection to reduce time waste and save costs. Inspectors can check the positions and readings of the sensors in the AR app as shown in Fig. 5a and Fig. 5b. If the inspector wants to know which sensor has abnormal data, thresholds can be preset based on the different types of sensors as demonstrated in Fig. 5c. Inspectors are allowed to send Inspection reports with the information of inspectors, locations, captures, and description to the web-based platform through the AR app. Users of the web-based platform can check the absolute location of the report in BIM model through the platform (Fig. 6).

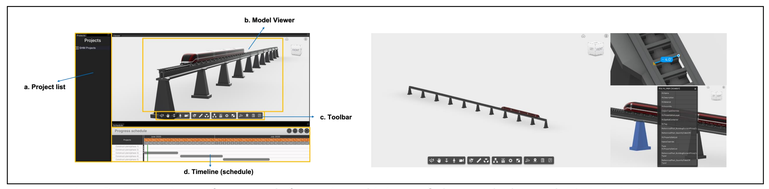


Fig. 2: User interface and functionalities of the web-based BIM-AR system

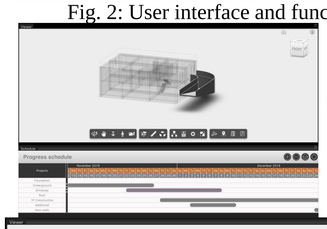
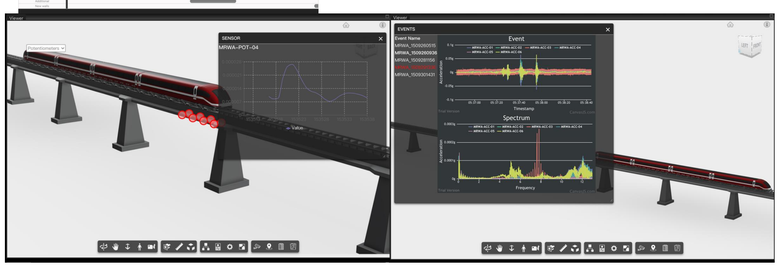


Fig. 3: Highlighted component of BIM model on the web-based platform



(a) (b)

Fig. 4: Sensor monitoring and simulation on BIM-AR

3. Result and Discussion

This project aims to develop a BIM-AR-based SHM system for better life cycle management of HSR infrastructure. The project works, as well as the expected functionalities of the systems, are completed successfully. They can be summarized into four tasks:

Task 1

Structural condition detection and monitoring. The developed BIM-AR system contains a web-based interface for displaying HSR and related infrastructure, further providing structural-related information. The users are able to highlight any of the structural components on the corresponding BIM model and get structural conditions for further examinations.

Task 2

Structural analysis, diagnosis, and prediction results. Based on the structural conditions collected from field infrastructure, the users of the developed BIM-AR system are allowed to manipulate the BIM model through different tools on the user interface and conduct further measurement and analysis.

Task 3

Inspection scheduling and resource arrangement. The developed BIM-AR system provides a flexible and user-definable timeline function for scheduling the construction/maintenance/inspection activities. They can be linked geometrically with the corresponding components of the HSR infrastructure.

Task 4

AR-enhanced on-site inspection and intervention. An AR app on portable devices is developed for the use of field inspection. It is an extension of the web-based BIM-AR system. The app helps inspector to superimpose the structural health information onto the HSR components in the real-world, further facilities an intuitive visualization for on-site SHM analysis. In the project, the users can examine the virtual sensor points and their corresponding readings through scanning a reference tag at field, as well as set up warning threshold for identifying sensors with abnormal readings. Further reporting of inspection results can be made and stored online where synchronized with the data in the developed BIM-AR system for further maintenance and resource management.

(a) (b) (c) (d)

Fig. 5: Sensor readings and abnormal sensors on AR app

(a) (b) (c)

Fig. 6: Create an inspection report and check reports