Efficient Inspection of Civil Engineering Structures for Railways and Roads Using Images and GNSS

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ABSTRACT

As structures deteriorate and engineers age, efficient maintenance and management of civil engineering structures becomes increasingly important.Alternative inspection of civil engineering structures using images is being recognized as an efficient inspection method.However, acquiring images of large and extensive civil engineering structures is time and equipment-intensive, which hinders mobility and is consequently not efficient. In addition, the management of existing civil engineering structures is highly specialized and lacks scalability, which means that significant effort is required to associate images with civil engineering structures.Therefore, we decided to acquire images of large and extensive civil engineering structures with video cameras to improve mobility and efficiency. In addition, as a key to linking images and civil engineering structures, we developed a technology to record latitude and longitude information as audio data in a video using GNSS(Global Navigation Satellite System) + dual-frequency RTK(Real Time Kinematic)This facilitates the rapid comparison of images and management data for existing structures with latitude and longitude information, as well as image data management in chronological order. This results in improved productivity in image-based inspection. In addition, AI processing of image data has made it possible to sample deformed areas and analyze geographical characteristics. These combined technologies have raised expectations for preventive maintenance of structures using images.

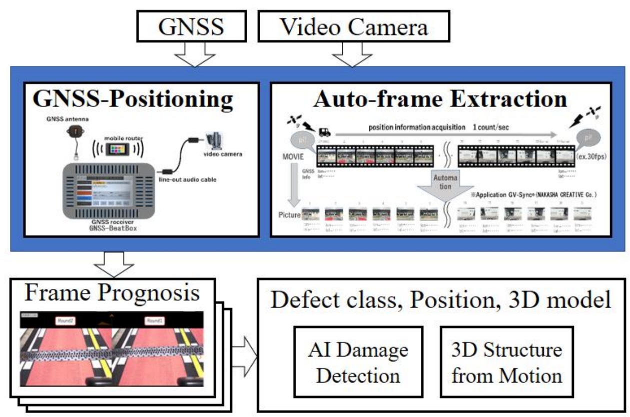

Figure. Product Overview Digital Inspection for Prognostics

1. INTRODUCTION

1.1 Related Works on Visual Inspection and Positioning

The application of image technology and sensors for inspecting railway and road structures includes dedicated systems that encompass on-site monitoring and management interfaces as well as automated inspection and correction using specialized vehicles [1-3]. In 1992, the "Nozomi" bullet train on the Tokaido Shinkansen line began operating at a speed of 270 km/h. In 2000, a test vehicle named T4, which was based on the 700 series and capable of reaching the highest operational speed, was introduced. Painted in yellow, this vehicle, known as "Doctor Yellow, " performs health diagnostics on electrical and trackside facilities [1]. For JR Tokai's existing lines, a test vehicle called "Doctor Tokai" was introduced in 1996 to comprehensively inspect tracks, electric train line facilities, and signal communication facilities. It runs at a maximum speed of 120 km/h and measures the track conditions of JR Tokai's existing lines twice a month.

In 2018, JR East Japan made significant progress in implementing a track facility monitoring system that allows monitoring track conditions remotely [2]. By 2020, it had been introduced into 50-line sections, covering 70% of the total track length. The track displacement monitoring device measures track distortions by projecting lasers onto the rails. The track material degradation monitoring device captures images using profile cameras to measure distances and line sensor cameras to detect variations in density, allowing the inspection of rail fasteners (rail fastening devices) that secure rails to sleepers and bolts (fishplate bolts) that connect the rail joints. This enables the implementation of condition-based monitoring maintenance methods, where the state of the tracks is assessed, and repairs are conducted at the optimal time [2].

Thus, monitoring systems for track facilities have been introduced on the Shinkansen and other major existing railway lines to monitor track displacement and material degradation. However, local lines often involve one-person train operations. Owing to budget constraints and the relatively short lengths of single-track sections, allocating dedicated inspection vehicles can be challenging. Considering the decreasing labor force and aging population, it is not realistic for staff to continue conducting visual inspections of the foot once a week. In local railway lines, there is a demand for a mechanism in which staff can easily attach video cameras to inspect track material degradation, rather than relying on remote monitoring devices installed beneath the floor of the train.

Deep learning has been proposed and experimentally studied for the classification and detection of rail fastener and sleeper variations during track material condition monitoring [4-6]. GPS is often used to determine position information; however, it can have measurement errors of several meters. To accurately determine the positions of detached rail fasteners and decayed sleepers and facilitate repair, the use of a Global Navigation Satellite System (GNSS) is required. Hazard sensing in image processing plays a vital role in the development of integrated maintenance planning systems as a crucial technology for condition monitoring. Risk-based maintenance methods, including sensor technologies, have also been proposed. Support systems for developing optimal repair plans considering the risk of derailment have also been established [7].

However, roads offer greater freedom than railways. Some methods utilize smartphones for the simple detection of road surface deterioration [8]. Moreover, inspection methods used on roads have been applied to railways [9]. However, previous research and inspection systems often require specifically designed cameras for image acquisition, and there are speed constraints on camera functionality during image processing.

Furthermore, most approaches utilize GPS for position information. However, the accuracy of determining the actual position is often off by several meters or more, making it difficult to identify a specific driving lane using GPS alone.

This study aims to develop an application that enhances the usability to automate image-position synchronization at image acquisition and improves the accuracy of position information for prognostic inspection and efficient repair towards railway components and road facilities

1.2 Objective and Our Application

The advancements in artificial intelligence (AI) technology have been accompanied by rapid progress in image analysis technologies. Image analysis technology is being used in various fields, including automated driving. Digitalization is progressively being used in the field of social infrastructure, and analog inspection methods have been progressively revisited for improvement. In particular, image-based alternatives to visual inspection have attracted attention.[10])

However, there are issues with image-based inspection methods. One issue arises during image acquisition. Currently, acquiring images of civil engineering structures that are located in large and wide-ranging areas requires a significant amount of time and manpower, and a large amount of resources is spent on post-acquisition data processing, though it is overlooked. Another issue is that even if deformation is determined by image analysis with only still images from the camera at the time of image acquisition, the position of the object cannot be identified, and work is required to search for the deformation location. An effective solution for addressing these issues in practice after image acquisition and image analysis involves supplementing the data by acquiring information from other sensors at the same time as image acquisition. One such sensor is the global navigation satellite system (GNSS) receiver. Combining GNSS information at the time of image acquisition makes it possible to record the position where the image was acquired, and the position of the target can be easily specified even after image analysis. The miniaturization of sensors in recent years has allowed for the embedding of GNSS receivers into familiar places, including smartphones. When an image is captured using a smartphone camera, the position information of the captured image is recorded, making it possible to know the location where the image was captured. However, many cameras with GNSS functions, including smartphones, are single positioning and have an error of 10 m for positional accuracy. This level of accuracy is often insufficient for safety-critical applications, such as those related to automobiles and trains, making it challenging to use such data for civil engineering structures. Relative positioning (RTK method) exhibits an error in the range of 20 mm to several meters, its accuracy is at an acceptable level.

Image acquisition by moving objects, such as trains and automobiles, is a highly mobile and efficient method of image acquisition of long and wide-ranging structures. The combination of GNSS and dual-frequency RTK enables the acquisition of images with high positional accuracy. The devices currently in use that can process two independent datasets at once are functionally complemented by some RTK-UAV (Unmanned Aerial Vehicle) and smartphone apps, but the equipment is highly limited and lacks versatility.

Therefore, currently, a method wherein the time is synchronized to match two independent images and GNSS data is used. However, given that the object being captured is mobile, once the GNSS and dual-frequency RTK reception is lost, the time of the image needs to be checked again. Further time synchronization work is needed when there are several photographic media because the photographic times of the respective media are different. As post-image acquisition organization requires manpower, the labor increases with data acquisition time. If the goal is to conserve manpower during inspection, it is difficult to improve efficiency when the images used increase the overall time. Therefore, herein, we discuss the development of two new methods, the obtained test results, and the application of the methods. We also discuss the efficiency of image inspection. The developed methods are as follows:

1. A highly versatile equipment capable of receiving GNSS signal and dual-frequency RTK and recording video.

2. A system that automatically processes acquired images and GNSS data into still images that can be analyzed.

2. MATERIALS AND METHODS

2.1. Development of Highly Versatile Equipment Capable of Receiving GNSS Signals and Dual-frequency RTK and Recording Video

In recent years, not only the high performance and miniaturization of electronic devices but also the expansion of open source software has made it possible to promote development, which was previously done only by some research institutions, relatively easily. Therefore, we used GNSS and dual-frequency RTK receiver and open sources to develop GNSS-BeatBOX ® (Patent 7148910: recording control device, recording system, and program), which converts GNSS signals into audio data.

The conversion of GNSS signals into audio data enables the embedding of GNSS reception information in all video cameras that support audio input, greatly improving the versatility of camera equipment. Additionally, distributing the audio output enables the input of audio from multiple cameras at the same time, making it easy to synchronize multiple cameras. For voice input, GNSS signals are received every second, converted to voice data, and then provided as input. The time lag from GNSS reception to voice input conversion is corrected during voice conversion.

2.1.1. Mechanism Structure

As shown in Figure.1, the GNSS-BeatBOX® comprises a GNSS logger(GNSS-BeatBOX®(NAKASHA CREATIVE)), GNSS signal-to-speech converter (QZNEO or QZNEO R(CORE)), Mobilerouter, High-precision positioning service: ichimill (SoftBank), Optional: video camera with audio input

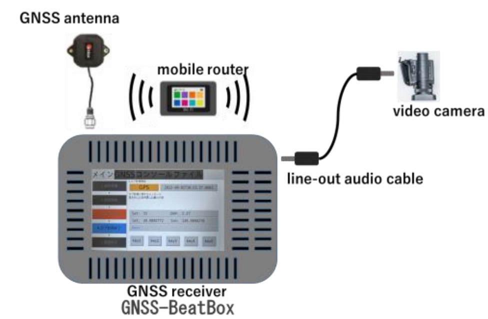

Figure 1. GNSS-BeatBOX®

2.2. Development of a System That Automatically Processes Acquired Images and GNSS Data Into Still Images That Can Be Analyzed

It is difficult to convert GNSS data and video audio data that were acquired in Section 2.1 into still images because of the GNSS data and information regarding distance traveled per second during high-speed movement are missing. Regarding the former, it is physically impossible to restore missing GNSS data. Therefore, the missing section was assumed to have a constant speed, straight movement, and a virtual point that was equidistant from the two points immediately before the missing GNSS data was determined and after the re-acquisition of the GNSS data was generated. Furthermore, the missing interval was corrected.

Additionally, the distance travelled per second increased with an increase in the speed of the moving object. Therefore, to compensate for this increase, virtual points that were obtained by equally dividing one second into camera frames were generated. This is dependent on various factors, such as camera installation position, distance from the object, lens angle, and frame rate. We assumed that the vehicle would not run at a speed where the wrap rate of one frame is less than 50%. For example, when the speed is 60 km/h and camera frame rate is 30 FPS, the movement speed per second ≈ 16 m/30 frames ≈ 0.5 m/frame. We developed the video processing device GV-Sync® (Patent 7100863: video processing device, video processing method, program) based on these functions.

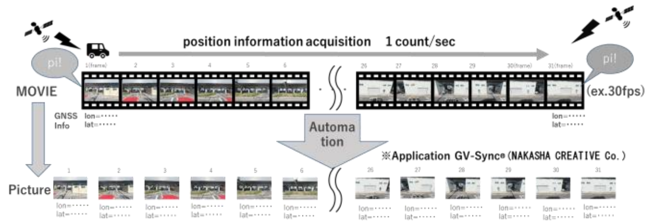

Figure 2. Mechanism of GV-Sync®

3. TEST RESULTS

3.1. Test

The tests were conducted on July 14, 2021 on the Nagoya Expressway Inner Circular Route (C1), an actual expressway, to evaluate the relationship between position information and images acquired by high-speed moving vehicles. The vehicle used was the Toyota Noah Hybrid. A 4KSDI camera was installed on the vehicle (Figure. 3) to shoot the road surface, and the GNSS-BeatBOX® was used to acquire GNSS and dual-frequency RTK information. Video was acquired with audio input, and processing was conducted with GV-Sync®. For the target, the vehicle was driven along the C1 route of the Nagoya Expressway Inner Circular Route for two rounds. Joints that were easy to compare were extracted from the acquired images, and the positional relationship was checked by arranging them side by side.

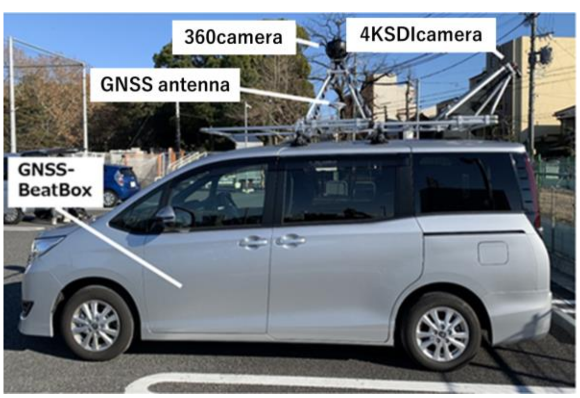

Figure 3. Shooting vehicle

3.2. Results

The trajectory of the acquired position information and extracted joints are indicated by the green dots in Figure. 4. We compared the positional relationship in the images of the two vehicles driven (Figure. 5). Please note that KP stands for kilopost, and 1 KP = 1 km.

Figure 4. Acquired GNSS data trajectory

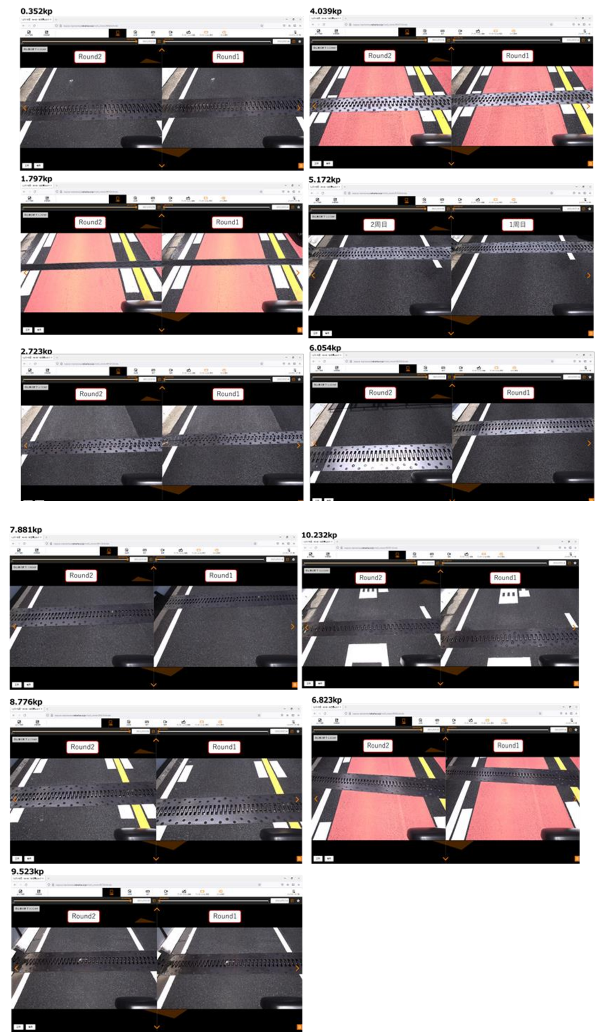

Figure 5. Comparison of position information and images acquired at two times

As shown in Figure. 5, a side-by-side comparison confirmed that, although there was a slight deviation, it was within one field angle.

4. APPLICATION EXAMPLES

Application examples of image analysis using GNSS-BeatBOX are described below.

4.1. Deformation Extraction by Deep Learning of Images on Side Walls of Expressways

Camera: FDR-AX700 (SONY)

Object extraction: YoloV3

Figure 6. Continuous image combination of sound barrier

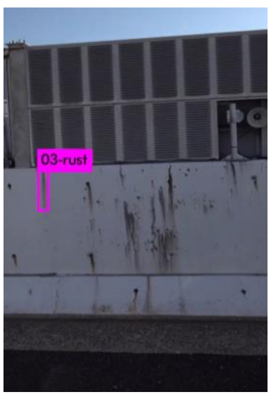

Figure 7. Object extraction from rust juice by deep learning of wall balustrade

4.2. Confirmation of Track Conditions From Inside Leading (Rear) Car on Railway

Camera: FDR-AX700 (SONY)

Figure 8. Continuous image combination of the leading image

Figure 9. Enlargement of continuous image combination

5. DISCUSSION

5.1. Method

Using the two developed methods reduced the effort needed to combine the location information and images. There was no need to record the time of data acquisition in seconds. Moreover, it was not necessary to open the GPS (Global Positioning System) log file after acquisition and confirm the position by advancing the image one frame at a time. Additionally, the fact that the position information can be assigned to all frames makes it possible to observe normal situations in chronological order. The results suggest that the method would be very effective in analyzing signs of deformation occurrence by retroactively investigating the locations where the deformations were confirmed.

5.2. Driving Tests

In the expressway tests, as the road conditions were so close to the ideal conditions (constant speed, no obstacles in the sky), the accuracy of the positional relationship of the images was enhanced. Therefore, there is a high possibility that the position of the image will deviate significantly in locations where the radio wave environment for GPS accuracy is weak. Correction of the image or correction by other sensors, such as those used for acceleration, is needed as a countermeasure.

Additionally, darkening and overexposure may occur in cases where it is difficult to adjust the brightness of the image owing to the effects of sunlight or shadows of buildings. Under such an environment, it is necessary to correct the image after image acquisition, or to conduct a field survey in advance for adjusting the exposure and setting the ISO sensitivity according to the environment.

5.3. Image Analysis Application

In this study, we implemented image analysis by conducting object extraction based on image recognition; however, there is a need to extract abnormality locations. It is currently difficult to create an object extraction model owing to the various characteristics of abnormality locations.

There are also many problems in analyzing the crack width, length, depth, and concrete flaking from images. Analysis of the width and length require certain conditions, such as maintaining a constant distance from the object. Currently, an effective approach is combining depth and flaking with other sensors. However, because a larger number of sensors makes coordination more difficult, we would like to avoid this issue.

6. SUMMARY

Using the present method for conserving image acquisition manpower is effective when inspecting structures using images. When the available data are only images and video, the use of the present method will not only conserve manpower but also provide highly useful data for preventive maintenance in the future. Thus, this method is highly recommended. Moreover, the influence of the surrounding environment, which is an external factor in data acquisition, remains an issue. There are many image analysis technologies that are positioned to support inspections. We would like to proceed with further research while considering the integration of image acquisition and feedback using such technologies. Our goal is to achieve a level of image analysis that can serve as an alternative to traditional inspection methods. For these reasons as well, we welcome cooperation with institutions that utilize image analysis technology.

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