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# Application of close range photogrammetry in remote railways infrastructure health monitoring

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## Abstract

Bridges are an essential part of railways infrastructure, and it is necessary to monitor their operation during their service life. To ensure the safety of a bridge, routine inspections are required to detect likely defect areas. Railway owners manage spread rail tracks and infrastructures, which one of the most important approach is structural health monitoring (SHM). It leads engineers to implement a package of measures for maintenance services, and follow serviceability and safety issues, which usually needs putting high amount of investments into that programs. Typically, a routine inspection consists of field measurements and visual observations made by a human inspector, and the main purpose of that is to collect documents of detected defects on infrastructures. In this study, remote inspection on a model generated by photogrammetry technique is discussed. In a practical way, by generating a 3D model with photogrammetry, inspectors can carry out visual structural health monitoring on a computer remotely. Hence, the generated model is compared with that of laser scanning, in terms of resolution and accuracy, and finally, the possibility of remote inspection of railways infrastructure is discussed.

**Keywords:** Photogrammetry, remote bridge inspection, railways infrastructure, 3D model generation.

## 1 Introduction

Structural health monitoring (SHM) is one of the most important approaches used by railway owners to manage rail tracks and railway infrastructure. SHM allows engineers to follow serviceability and safety issues by implementing monitoring measures. As SHM might require high amounts of investment, railways managers all over the world are continuously looking for simple, inexpensive, and yet practical ways to perform structural health monitoring. For this reason, there is the needed to find modern techniques with sufficient accuracy and productivity.

For instance, SHM still depends on traditional inspection survey. Typically, such surveys consist of field measurements and visual observations made by a human inspector. Their main purpose is to document damage on the surveyed assets. The documentation of the data still relies on paper-based documents (e.g., field notes, freehand sketches), photographs, and it is not well organized for follow-up routine inspections. In addition, the procedure is highly dependent on the inspector's experience and knowledge [1]. It needs to be mentioned that, usually, inspections in hard to access areas are not performed correctly due to all the existed difficulties and risks. This is especially true for large-scale structures, such as bridges, where investigating the whole area can be highly time-consuming and potentially unsafe. Graybeal et al. (2002) [2] noted that routine inspections have relatively poor accuracy, due to inspector's fear of traffic, near visual acuity, color vision, accessibility, and complexity. Furthermore, when different inspectors carry out the investigation, knowledge transfer from one inspector to another becomes difficult.

As an alternative to traditional visual inspections, close range photogrammetry (CRP), which is a contactless sensing method, has received considerable attention due to its high productive data acquisition together with its low cost and robustness to work in any climate/environment condition [3] [4]. Due to the exceptional advances in computer power, memory storage, and camera sensors in last decade, it is expected that photogrammetry inspection slowly replaces traditional surveys. In this study, photogrammetry is used to generate a 3D model of railway infrastructure that can be used for remote infrastructure inspection. By generating the 3D model, inspectors can carry out visual structural health monitoring on a computer remotely, without the risk of safety and time constraints of the field environment. As verification, a 3D point-cloud is generated by laser scanning to discuss the performance of photogrammetry in remote inspection.

## 2 Methods

The concept of photogrammetry is making a precise 3D model of an object from two-dimensional images. The basic steps of photogrammetry involve: (1) Image acquisition, (2) detecting features within each image, (3) matching these features in multiple images, (4) reconstructing their relative 3D position in the observed scene, and (5) 3D model generation as a result. Figure 1 illustrates the typical processes used in each step and provides a framework for the following discussion.

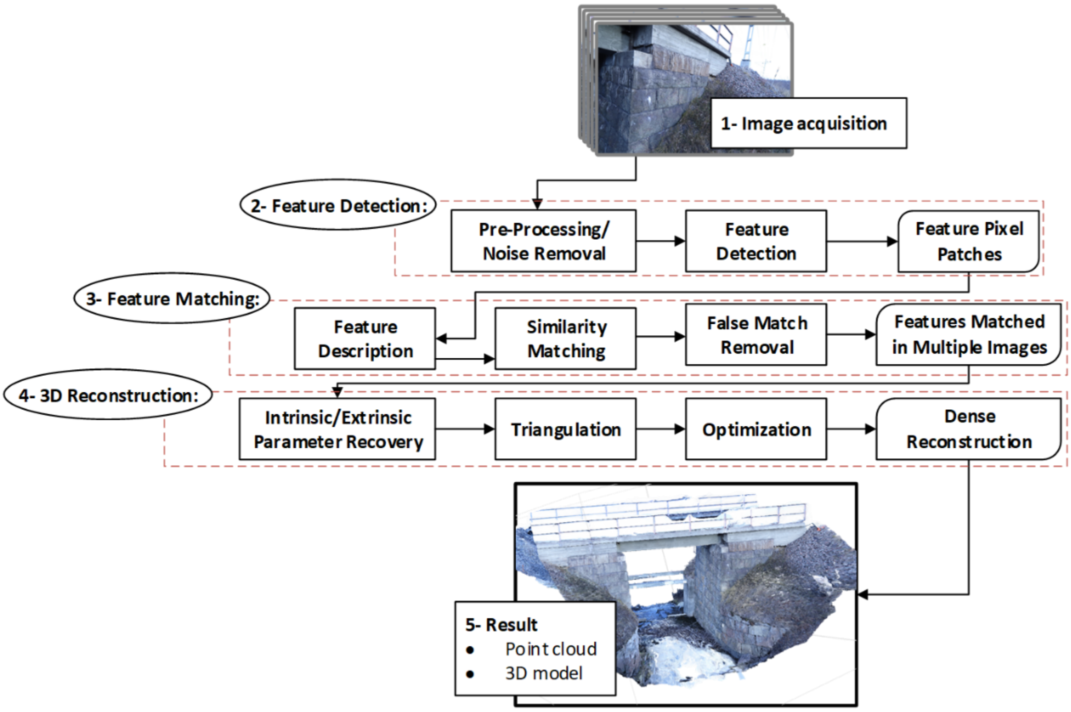



Figure 1: Photogrammetric reconstruction process.

In this paper, 3D model generation is performed by a commercial structure from motion (SfM) software package, Agisoft PhotoScan Pro (LLC, 2017), which simultaneously determines the interior orientation and defines the orientation of the camera position for each photo relative to the scanned object. To make the process easier, the surfaces of the imaging object should have distinct features, either natural (e.g. sharp edges, discoloration, bolts, or rails) or artificial targets. A minimum of 60% overlap between images is also necessary, in both the longitudinal and transversal directions [4].

The equipment used for close range photogrammetry (Figure 2-a), consisted of a DSLR camera Canon EOS6D Mark II with a full-frame (35.8*23.9 mm) complementary metal–oxide–semiconductor (CMOS) optical sensor giving a resolution of 12.8 megapixels (4368*2912 pixels). The camera was equipped with Canon EF 24mm, and 20 mm wide-angle prime lenses.

The equipment used for laser scanning was a long-range, RIEGL VZ-400, 3D terrestrial laser scanner (Figure 2-b). This 3D scanner operates on the time-of-flight principle and can make measurements from 1.5m to 600m with a nominal error of 5mm at 100m range. The raw terrestrial laser scanning (TLS) data was post-processed (registered and geo-referenced) using the Leica Cyclone software package, which automatically aligns the scans and exports the point cloud datasets for further processing.


(a) (b)

Figure 2: Data acquisition Equipment. (a) Canon EOS6D Mark II digital camera with lenses, (b) RIEGL VZ-400, 3D TLS

In order to use the generated model for remote inspection, it must have sufficient accuracy and resolution to represent the types of small-scale visual details that inspectors look for during an inspection. With this aim, the quality of the images can be measured with ground sampling distance (GSD). The GSD equals the distance between the centers of two consecutive pixels on the target surface. Ideally, a smaller GSD value is better, but the field of view (FOV) value should be considered as well. As FOV represents the area covered by the camera, a larger FOV minimizes the number of images required for data collection [refer to Chen et al. [5] for further details].

## 3 Results

The Juovajokk Bridge, close to Abisko in northern Sweden, built in 1902 with the superstructure replaced in 1960, is considered as the case study. This bridge is a simply supported trough bridge with a span of 5.5m and a width of 3.8 m. The surrounding area is densely vegetated and there are steep slopes behind the abutments, it was difficult to stand tripod for image acquisition. Figure 3 shows the positions of the camera during data acquisition. Please notice that points 8-13 in Figure 3 are located underneath the bridge.

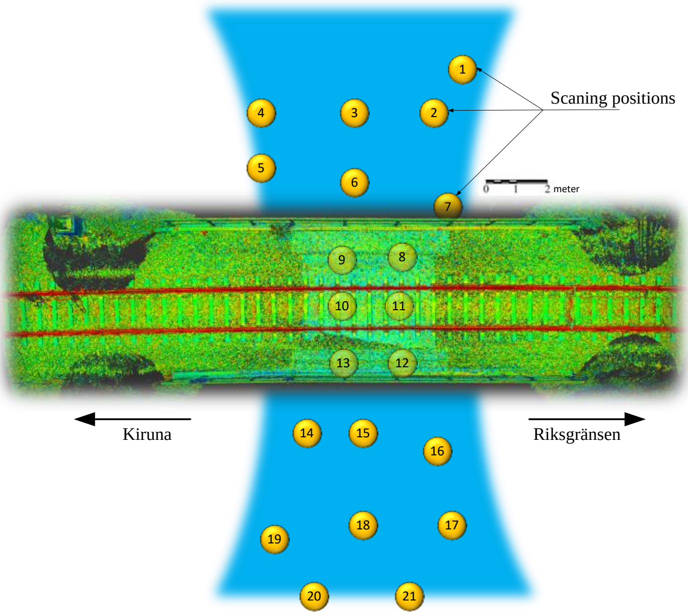



Figure 3: Scanning positions in photogrammetry for the Juovajokk Bridge.

Both CRP and TLS surveys were carried out on a cloudy day, with easy set-up facilities and high productivity for CRP, and 3D point clouds were successfully generated from both scanning methods (see Figure 4). Both generated point clouds were imported into Autodesk ReCap to extract measurements, such as the bridge structural elements, and inspect the bridge remotely. Bridge inspection in hard to access areas performed without all risks and safety issues. The existing as-built drawings were used to establish the ground truth, and both methods provided good accuracy with low deviation, as can be seen from Table 1.


Figure 4: Measurements of bridge structural elements in both CRP (left), and TLS (right) method

| | | TLS | | CRP | |
|---|---|---|---|---|---|
| **Component** | **As-built dimension (mm)** | **(mm)** | **%ΔL** | **(mm)** | **%ΔL** |
| **Span** | 5500 | 5432 | -1.2% | 5456 | -0.80% |
| **Width (deck)** | 3800 | 3805 | 0.13 % | 3810 | 0.26% |

Table 1: TLS and CRP accuracy comparison

Generally, generated point clouds include missing data, inaccurate geometric positioning [6], surface deviation [7], and outlier noise [8]. Each type of mentioned errors described in detail by Chen et al. [5]. Figure 5 shows confidence model presenting the confidence of triangulation in each part of model. All the noises and errors illustrated by warm colors, and cold colors showed more confident in triangulation.

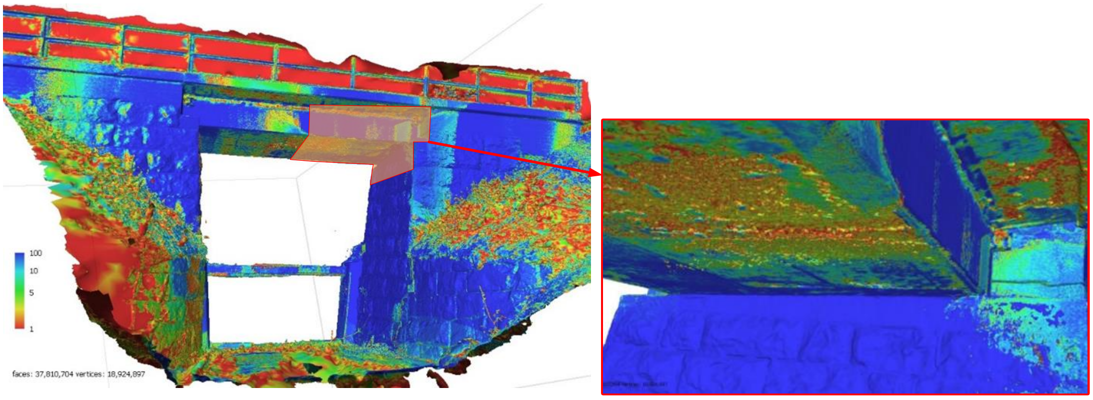
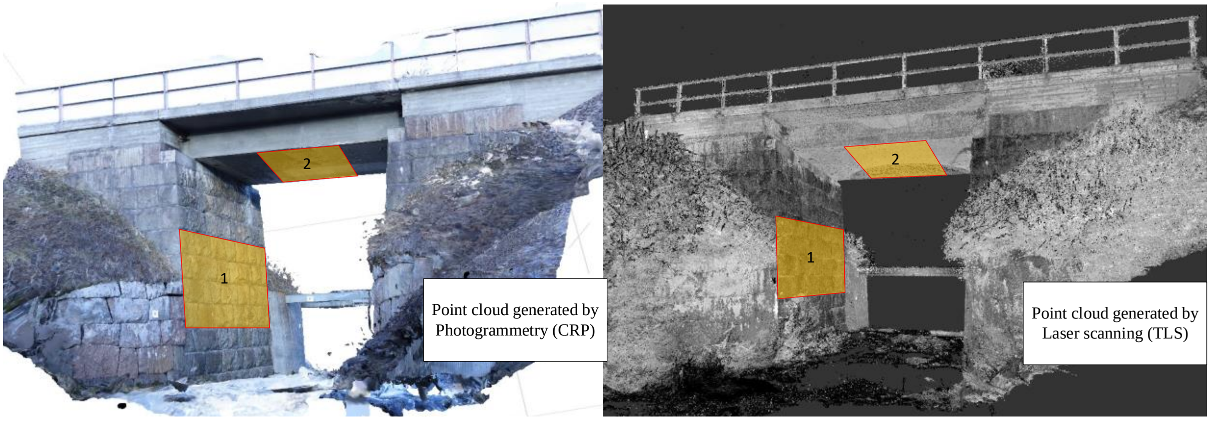


Figure 5: Confidence model of Juovajokk Bridge, blue parts have reliable triangulation and red parts include noises

From the rendered viewpoint, based on a naked eye assessment, there is not much to distinguish for the quality of the two generated models. The comparison of the point cloud density for the two different scanning methods is presented in Table 2 for the two areas shown in Figure 6. Based on the results, a higher point-cloud density does not necessarily present more details with higher resolution. In this case, despite the high point-cloud density of CRP, its outlier noises were also higher than those of TLS, which needed to be decreased by a noise removal method as a post-processing step. Point cloud deviation of photogrammetry regarding laser scanning is illustrated in Figure 7, for both areas.




(a) (b)

Figure 6: Intended areas in abutment and underneath the bridge for both CRP (a) and TLS (b) models

| Area | Intended area ($m^2$) | Reconstruction method | Number of points | Local point density (points/($m^2$)) |
|---|---|---|---|---|
| **1- Abutment** | 13.97 | TLS | 1,342,556 | 96,103 |
| | | CRP | 1,391,184 | 99,584 |
| **2- Underneath** | 8.23 | TLS | 1,297,370 | 157,639 |
| | | CRP | 1,883,544 | 228,863 |

Table 2: Resolution level comparison

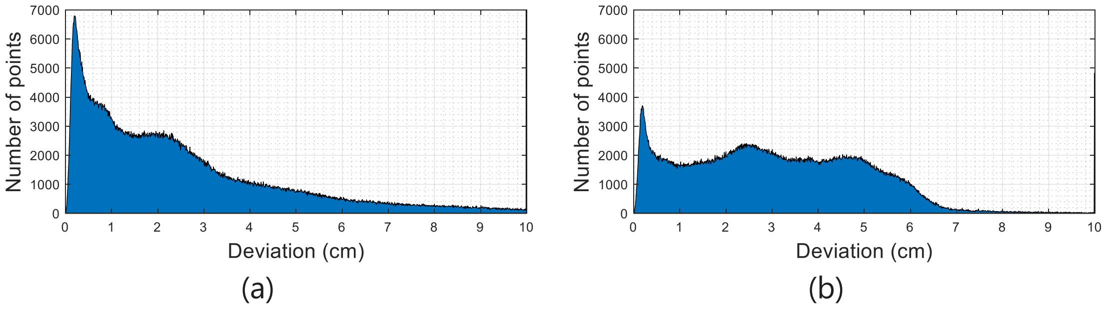



Figure 7: CRP point cloud deviation regarding TLS point cloud, which is considered as a reference, in area 1 (a) and area 2 (b)

As illustrated in Figure 7, there are more outlier noises in underneath the bridge (area 2) than in area 1. This is mostly caused by the light condition and lack of distinct features in the pattern that subsequently affected the mesh generation and the surface reconstruction.

# 4 Conclusions and Contributions

The proposed method uses photogrammetry to generate a 3D model of a exiting bridge with the aim of providing railways owners with a remote inspection and documentation method that is more reliable and accessible than traditional surveys. Based on the results presented and the state-of-the art in the topic, the following conclusions can be drawn:

1. Close-range photogrammetry (CRP) offers several benefits compared to conventional monitoring methods including:
    - Remote monitoring in difficult to access areas, without any safety issues
    - Accurate enough data acquisition with high productivity
    - Easy set-up facilities and reducing specialized operator requirements.
2. CRP is more efficient and cost-effective compared to the laser scanning, but improvements in automation during the image acquisition phase are still required. For instance, with respect to railways infrastructure inspection, image acquisition can be handled with unmanned aerial vehicle (UAV), approaching autonomous 3D model generation.
3. Outlier noise usually appears around the boundary of the structure due to scene complexity, surface texture, shadows, or light reflection, and tends to confuse the triangulation procedure in photogrammetry. Then, further studies needed to eliminate outlier noises.

There are still drawbacks in application of CRP including long post processing time, and the higher computational resources when compared to those required for laser scanning. Hence, it is suggested to generate a hierarchical 3D model with high resolution just in areas of interest, instead of acquiring high-resolution information for the whole inspected infrastructure.

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