Construction and Building Materials 146 (2017) 668–678

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Assessment of cracks on concrete bridges using image processing supported by laser scanning survey

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HIGHLIGHTS

- Evaluation of crack is important to maintenance of concrete bridges.
- MCrack-TLS method is proposed to automatically assess cracks in concrete bridges.
- The method combines image processing and terrestrial laser scanning technology.
- MCrack-TLS provides automatic and accurate processing.
- A comprehensive 3D models of the state of conservation of the bridge is produced.

ARTICLE INFO

Article history:
Received 15 February 2017
Received in revised form 10 April 2017
Accepted 12 April 2017

Keywords:
Bridge assessment
Crack detection
Crack monitoring
Image processing
Photogrammetry
Laser scanning

ABSTRACT

The accurate assessment of the state of conservation of concrete bridges is extremely important to define maintenance strategies and to optimize interventions. In this regard, crack detection and characterization plays a particularly important role. However, several limitations are found in current evaluation techniques. In fact, these are work-intensive, prone to human error, and they often require the use of expensive inspection means, such as under-bridge trucks. In this scope, the development of automatic methods based on image processing and laser scanning to assess cracks in bridges has significant advantages.

In this paper a novel method, MCrack-TLS, is proposed to automatically assess cracks in concrete bridges, based on the combination of image processing and terrestrial laser scanning (TLS) technology. The images captured are orthorectified by geometric information surveyed by TLS, solving one of the major drawbacks of applying image processing for cracks characterization on large structures. After an experimental characterization, the method was tested on a concrete viaduct at IC2 road, in Rio Maior, Portugal, herein adopted as case study for onsite validation. It should be noted that capturing images with the required characteristics involves the use of different equipment, depending on both location and type of structural members. The results show the high potential of MCrack-TLS, namely its increased productivity and the possibility of record all data processed, and add it to 3D point clouds, creating 3D models of the state of conservation of bridges. In addition, it avoids the exposure of bridge inspectors to dangerous situations.

1. Introduction

Governments and private companies worldwide have made a significant investment in civil infrastructures in the last decades. Their maintenance must be understood as a priority to ensure safety, and interventions should be defined to minimize both costs and environmental impacts. The latter become more relevant due to current climate changes, which should lead to new maintenance strategies. Thus, R&D priorities have to be focused on the development of solutions that ensure suitable surveys and direct analyses of the state of conservation of structures, aiming at achieving a fast and reliable diagnosis. Furthermore, regarding the current socio-economic and environmental challenges, early detection of damages allows for an effective, economical and less intrusive intervention.

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http://dx.doi.org/10.1016/j.conbuildmat.2017.04.096
0950-0618/

Anomalies in concrete bridges can be due to imposed or restrained deformations of the structure, chloride ingress and carbonation of concrete, corrosion of steel rebars (caused by the latter), and biological colonization, among others. A correct inspection of the structure is mandatory, in order to get an accurate diagnosis and, in this scope, the crack pattern characterization plays a very important role.

Traditionally, bridge inspections are performed periodically and are based on visual assessment. Besides specific equipment, special vehicles are also required to allow inspectors to get close to the bridge members, including below the deck. These are currently named 'under-bridge trucks' and represent a very significant share on the inspection costs. For this reason, the state of conservation is always assessed only at critical areas, instead of exhaustively. This also turns difficult to monitor cracks and other anomalies of the same areas over time. In addition, the inspection is performed in a narrow band of the electromagnetic spectrum, because human eyes are limited to the visible range. All these current limitations can be overcome if the manual practices are replaced by automatic, accurate, cost-effective, fast and easy-to-implement methods [1,2]. In this scope, the automatic characterization of the state of conservation of infrastructures should take advantage of all technological developments, and create solutions by settling synergies between the different research areas involved in this frontier research line. In the last decade image processing technics have been applied for detection and characterization of cracks on concrete structures [3,4]. However, most of the methods were validated in laboratorial environment, and a gap to scale-up them to existing structures is clearly identified. The problem is directly related to the lack of geometric information that allows to align and scale the images acquired.

In this paper, a novel method is proposed, named MCrack-TLS, combining Terrestrial Laser Scanning (TLS) technique and image processing procedures previously validated [1], based in image processing techniques to automatically identify and record crack characteristics in concrete bridges. The parameters evaluated are the width, length, orientation and location of cracks. The procedure applied is based on the use of two methods developed and validated in the last decade [3,5]. In this case, the results are improved by join both methods, who previously worked separately. On the other hand, one of the major drawbacks to its onsite application, mainly in large structures, is the need for image orthorectification. The latter includes image transformations for distortion correction, 3D rotations, and scaling, which are directly computed through the calculation and application of homography matrix [3]. Thus, real coordinates (in mm) of, at least, four reference targets are required. The method proposed, MCrack-TLS, allows to overcome this disadvantage, since provides the required information from the 3D data recorded by TLS.

The content is organized as follows. After this introductory section, a background section follows, highlighting the existing practices, equipment and technologies in use for structural assessment, and most specifically for cracking evaluation. Next, Section 3 explains the methodology developed for crack detection and characterization and its validation in laboratorial environment. Section 4 focuses on and discusses the results obtained from a field test carried out on a concrete viaduct. Finally, Section 5 lists the main conclusions drawn in the scope of the study conducted.

2. Background in bridge assessment

2.1. Traditional assessment

The existing methods for evaluating the state of conservation of concrete bridges are based on different procedural levels: routine, detailed or special inspections [6]. In particular, bridge inspectors should look for the typical signs of damage and deterioration, namely spalling, scaling, leaching, dampness, corrosion, delamination and cracks [7]. Cracks in concrete do not necessarily represent a risk for the structure or even vulnerability. Therefore, they must be carefully characterized by structural engineers aiming to identify the probable causes and preview the expected consequences.

The inspection practices for reporting the presence of cracks are usually described by direct sketches based on visual observations, either using a hand-held measuring magnifier (Fig. 1a) or a crack width ruler to measure crack openings (Fig. 1b). However, these manual approaches exhibit the disadvantages above-mentioned, while their advantages are related to the physical and close contact with the crack, which can prevent false detections. In order to have an efficient crack detection, it is frequently required the use of very expensive means of access, ensuring not only suitable inspection conditions but also the safety of the maintenance crew. The inspection quality will depend on the type of access provided [6], being the latter dependent on the cracks' location and particular requirements. For instance, under-bridge trucks assist the inspectors in gaining close access to the damage (Fig. 2), though important drawbacks can be pointed out: (i) high costs associated with the use of these platforms, (ii) long execution times, and (iii) interruption or limitation of traffic flow. Alternatively, the technicians can rappel the structure for a hang-on evaluation of a crack.

2.2. Vision and laser systems

The widespread availability of optical and digital equipment gained in the last two decades led to an opportunity for several applications including structural assessment. Laser scanning and image processing have been increasingly applied with positive results [8–10].

Currently, TLS technology has already been broadly applied in architecture, engineering and construction sector for geometric survey [11], structural health monitoring [12,13], structural assessment [14,15], deformations measurement [16], and damage detection [17], the latter including crack detection [18]. This technology accurately collects 3D measurements of structures, providing both quantitative and qualitative information, discretized as a point cloud (Fig. 3). Disadvantages are also identified: the technology is heavily dependent on the scanner positions, the scanning range is limited (usually 100 m to 1400 m), and high execution time and cost are needed.

Terrestrial photogrammetry has been used for structural characterization and monitoring, particularly for 3D geometric assessment [11,19] (Fig. 4) and for displacement monitoring of masonry bridges [10,19]. Photogrammetric techniques discard the need for access platforms, allowing high-resolution and cost-effective imaging of the structures. Likewise laser scanning, it requires a proper positioning of the photographic stations (access and field of view) and it can also involve the need to acquire a large number of images.

Image processing can be used in the automatic evaluation of cracks [3–5] or in the damage assessment of concrete surfaces [20]. Recently, a first approach of a method resulting from the combination of different techniques [1] was developed, allowing the characterization of: (i) cracking patterns [3]; (ii) displacement and strain fields in structural members subjected to load [10,21]; and (iii) areas of biological colonization, moisture, exposed aggregates, repairing mortar, among others [20]. The automatic characterization of cracks on surfaces presents the following main advantages compared to traditional methods: (i) being automatic, it is immune to human error, (ii) the entire cracks' length is measured; (iii) crack monitoring is performed at exactly the same position(s) over time; and (iv) higher precision and accuracy can be