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Taxation of cracks on concrete bridges using image dispensation supported by laser scanning study

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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, and 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 Major, 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.

Key words:-MCracks-TLS,3D-Models.

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 dam- ages allows for an effective, economical and less intrusive in 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 geo-metric information that allows aligning and scaling the images acquired.
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.

1. BACKGROUND IN BRIDGE ASSESSMENT

Traditional assessment

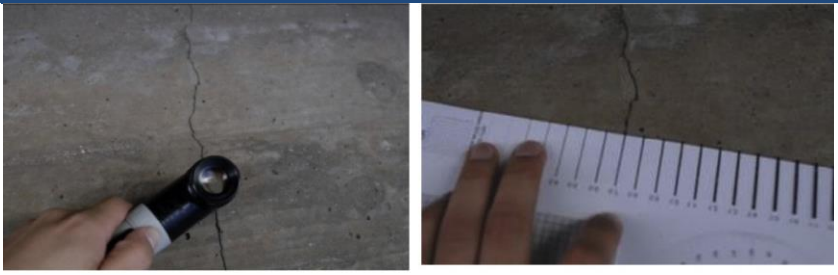
The existing methods for evaluating the state of conservation of concrete bridges are based on different procedural levels: routine, detailed or special inspections [6]. In particular, bridge inspectors should look for the typical signs of damage and deterioration, namely spalling, scaling, leaching, 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.

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 reached. The major drawbacks consist on the requirements for adequate image quality and resolution that can be difficult to achieve in inaccessible locations of the structural members, and on the survey of geometric information to compute image orthorectification. Lastly, it should be referred to that most of the methods previously mentioned were developed and calibrated in laboratorial environments and, thus, further developments are needed before they can be broadly applied to existing structures.



(a) (b)

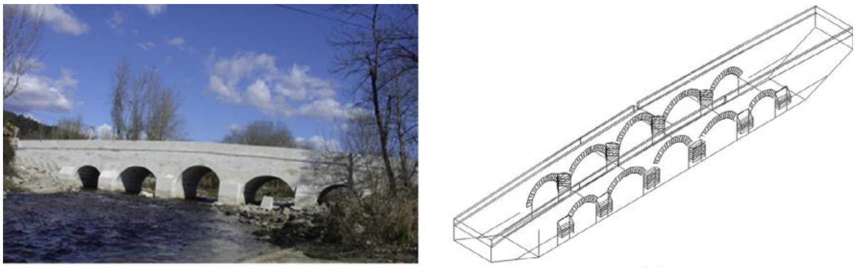
Fig. 1. Manual measurements of crack widths: (a) measuring magnifier; (b) crack width ruler.

(a) (b)

Fig. 2. Under-bridge truck: (a) parked on top of the bridge deck; and (b) platform to access below the bridge deck and the supports.

(a) (b)

Fig. 3. New Bridge of Ourense, Spain: (a) overview; (b) 3D geometric model (point cloud) obtained by laser scanning.



(a) (b)

Fig. 4. Bridge of Vila Fria, Portugal: (a) overview; (b) 3D geometric model obtained by photogrammetry.

State-of-the art analysis

The last two sub-section clearly evidence the gap between state-of-the-art technologies and the current bridge assessment procedures. They also indicate that future developments should consider the integration and the synergies between the innovative technologies. The current isolated use of those technologies should be changed for developing more robust and efficient methods. In the particular case of crack measurement, image processing fails when applied to real structures, since image orthorectification is demanded. However, all the information required to perform that transformation can be provided by TLS. The proposed method intends to suppress the technological mismatch above mentioned, by using TLS data to compute the orthorectification of the high resolution images acquired. These innovative approaches will allow to apply methods previously restricted to laboratorial environment in large structures, contributing significantly to the evaluation of cracks in concrete bridges.

2. MCRACK-TLS- ASSESSMENT OF CRACKS ON CONCRETE BRIDGES

Procedure

The flowchart of the method 'MCrack-TLS' Assessment of Cracks on Concrete Bridges is presented in Fig. 5. The method is organized in two major categories: (1) TLS which, initially, operates independently, and (2) application of image processing and analysis based on improving and merging two methods previously developed [3,20] that starts next, and then is performed simultaneously. Except for the point cloud generated by laser, the algorithms were implemented in Matlab environment [22].

Terrestrial laser scanning

Laser scanning is used to perform the 3D geometric survey of the structure, i.e., some or all of the structural members. This information is used to compute the image orthorectification, required to apply the image processing procedure. Depending on the distance to the object and the resolution of the equipment, it is also possible to identify discontinuities through the analysis of the intensity data and its geometrical properties. The procedure comprises the following main steps:

1. Acquisition of point clouds and post-processing procedures;
2. 3D model reconstruction (3D local and global coordinates of the reference points);
3. Identification and record of reference target coordinates for image rectification;
4. Segmentation based on the intensity values [23];
5. Detection of surface discontinuities
    - Definition of a reference plane;
    - Calculation of the distances-of-plan standard deviation; and
    - Classification of points in discontinuities (possible cracks) or concrete surface.

In the first step, before data acquisition, a survey of the site should be performed to define the scan positions required to optimize the capture of the target object. Once the TLS data sets are collected, a post-processing procedure is applied to remove noise and redundant data. In step 2, the local coordinate point cloud are transformed into a global coordinate system. Analytically, this transformation involves the calculation of rotational and translational parameters analogously to photogrammetric procedures. In the third step, the coordinates of the selected reference targets are recorded to be used in image rectification (the 2nd step of image processing procedure). At least, four coplanar reference tar- gets are required. In the fourth step, intensity values varying for different surfaces depending on their characteristics are analyzed. Laser scanners record a measure of the returning laser beams together with range and angular measurements. It is referred to as intensity or reflectance value, and it corresponds to the relation between the power of the reflected laser beam with respect to the power of the emitted one. The recorded return pulses vary in their intensity due to several factors, including the physical characteristics of the target surfaces (e.g. surface roughness or moisture con- tent), and others such as the angle of incidence, the atmospheric conditions or the distance between the scanner and the object. Commonly, the intensity value recorded from the voltage level of the photo detector is digitalized in the range 0–1 or 0–255 (8 bits), as occurs with digital images. In gray-scale point clouds, cracks present themselves as dark regions with minimum values of intensity while points belonging to a smooth surface commonly show higher intensity values. As a consequence, it is possible to first apply a filter based on intensity. However, false crack points can be introduced and, therefore, a post-refinement of the method is necessary, being explained next. Step 5 is used for classifying the surface discontinuities, by first estimating the normals to the surface in the point clouds segmented in Step 4, and then fitting a reference plane, and lastly computing the orthogonal distances between all points and the plane. The following operations are pro- vided in detail: Local neighborhoods of fixed size are computed for each point using K-Nearest Neighbours search (KNNsearch [24]). The estimated normal surface for point P is assumed as the normal to the plane that best fits the neighboring data points in the least square sense. This plane is determined using Principal Component Analysis (PCA) [23]. It should be noted that, for high curvature surfaces, it is mandatory to slice the data point cloud in order to obtain a better adjustment of the corresponding planes. For each resulting cluster, its centroid and the mean surface normal vector are computed. Those are then used to fit a plane to each cluster of points, defined by the points not classified as discontinuities during the previous step. Lastly, the standard deviations (r) of the orthogonal distance of points within the point cloud to the plane or planes created are computed. A threshold is used to classify the points as being on the surface or inside the cracks. If the corresponding distance is farther than 2r, then the point position is marked as a crack. Otherwise, it belongs to the concrete surface. This is the adopted general procedure when minimum crack widths can be detected. However, for those cases where the laser beam presents difficulties in penetrating inside the cracks, the automation could fail, e.g., it would be difficult for it to distinguish between a corner and a crack. Thus, this can be important tool for experimental application but, for on site evaluation of large structures, the detection of discontinuities such as cracks is not expected.

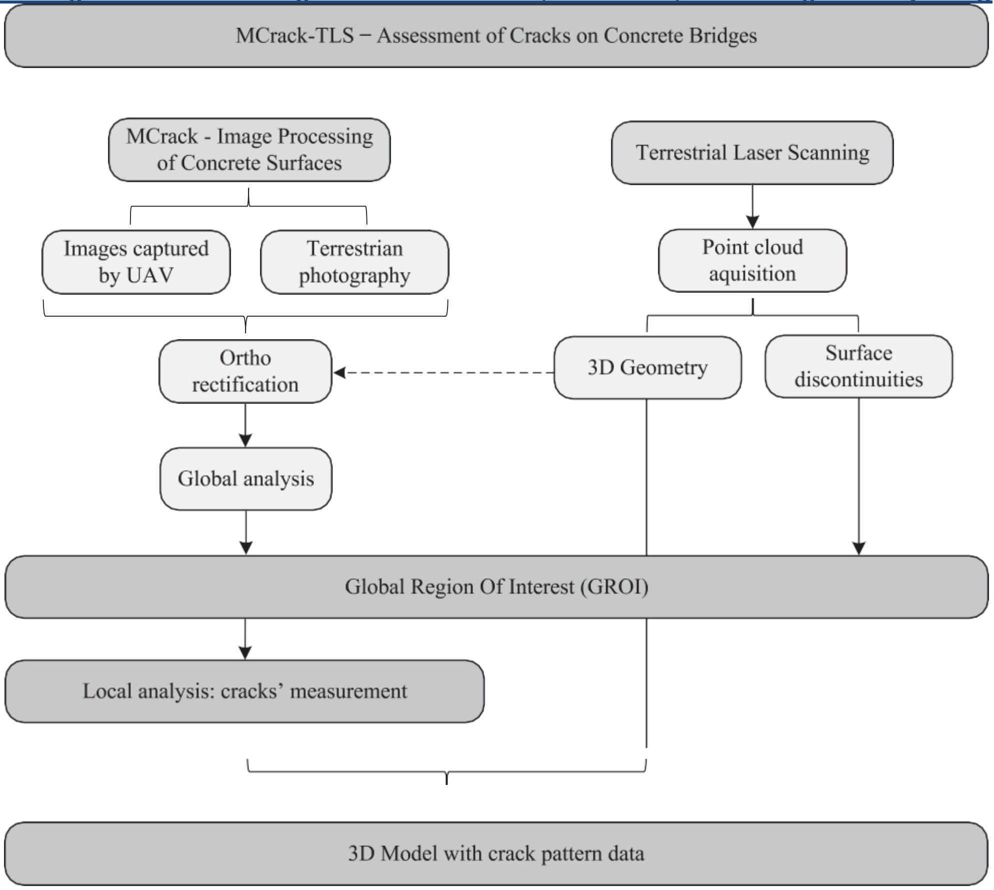


Fig. 5. Flowchart of the 'MCrack-TLS' method.

Image processing and analysis

The identification and characterization of cracks is achieved by merge two methods previously validated, one based on multi- spectral analysis [20], and another based on photogrammetry and image processing [3,5]. The result ended in the following procedure:

1. Image acquisition [25];
2. Image rectification in order to produce orthorectified images [10,26];
3. Global analysis to identify discontinuities through multispectral analysis [3,20];
4. Definition of the region of interest [3,5];
5. Local analysis of the regions of interest [5];
    - Identification of the crack borders [3]; and
    - Measurement of the crack opening [3];

In the first step, a careful planning of the photographic survey is essential to cover all critical areas with the required precision for crack identification and measurement. In Step 2, the image distortion and scaling is computed using a Homography matrix, estimated with the support of the reference targets provided by laser scanning [5]. In the third step, the global analysis consists in the application of the method based on multispectral image analysis, previously developed [20], to identify cracking areas. The procedure selected consists in computing an unsupervised classification by applying Iterative Self-Organizing Data Analysis Technique (ISODATA) ISODATA algorithm [20,27]. In Step 4, the Global Region of Interest (GROI) is identified from the outputs of the previous step [3]. The GROI results from areas with high density of discontinuities. Finally, in Step 5, the GROI is automatically divided into Local Regions of Interest (LROI) and digital image processing techniques [5] are applied to each LROI. In cases where the boundaries of the cracks are interrupted, the user can subdivide it by selecting those points, in a semi-automatic procedure. Finally, the user can select any of the cracks identified, the cracks boundaries are detected and its coordinates, discretized by pixels, recorded. The information of both boundaries of the selected crack allows to automatically perform the cracks characterization, and a report with all its relevant parameters (location, width, length, date) is recorded.

Outputs

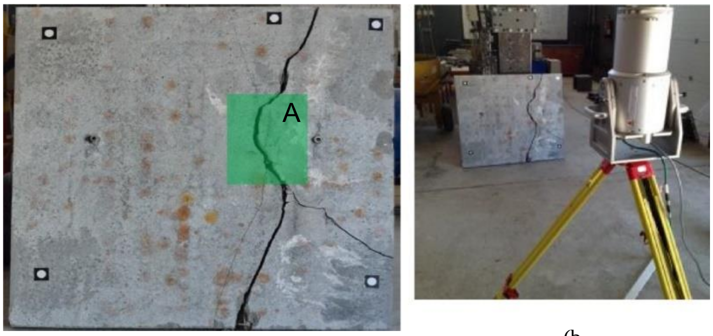
The information acquired from the TLS survey allows to build detailed 3D models from the point cloud. Thus, the final crack pat- tern can be overlaying on the 3D model the bridge, taking into account the coordinates of the reference targets.

3. EXPERIMENTAL VALIDATION

The validation of the proposed method was performed using an experimental model of a concrete slab previously tested up to fail- ure. The main gold of this validation is to test the merge of data from both technologies used by the method proposed. It was sur- veyed using both: (1) a terrestrial laser scanner RIEGL LMS-Z390i, placed at 2.5 m from the specimen and with an angular variation of 0.005°. The density of the resultant point cloud is approximately 650 points/cm2. The accuracy specified by the manufacturer's, independent of the object's color, is 6 mm at 50 m. This value was assumed to be the accuracy of TLS for the whole study; and (2) a digital camera Nikon D3100 with 4608x3072 pixels, placed at 2 m from the specimen, which result in a spatial resolution of 0.35 mm/px. Five high accuracy targets were placed on the slab surface and used as reference targets (Fig. 6).

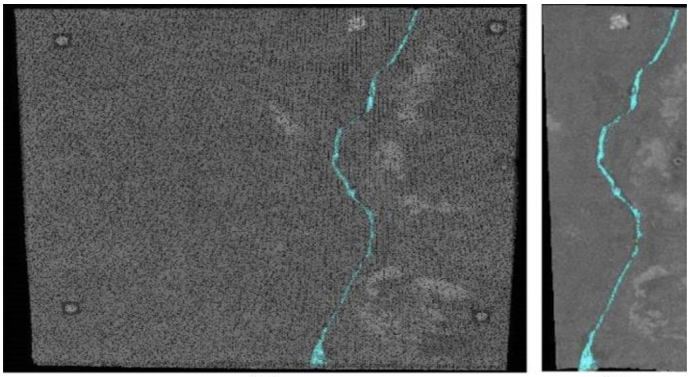
Fig. 7 shows the final intensity maps compute from laser scanning. The defined procedure allowed to identify the entire crack. For this experimental case, the spatial resolution of LiDAR data is around 0.2 mm on a target surface. This results from the use of a fixed angular separation of 0.005° at a close range of 2.5 m from the specimen and a beam divergence of 0.3 mrad. The latter corresponds to an increase of 30 mm of beam diameter per 100 m distance, lower than 1 mm at 2.5 m.

Fig. 8 shows the outputs of the main steps performed to characterize the crack with image processing. The orthorectification of the image was computed using the input coordinates of the reference targets obtained by laser scanning. The overall analysis allowed the identification of the crack (Fig. 8a) and the subsequent local analysis in the discretized area (Fig. 8b-c) allowed to measure its opening (Fig. 8d). The measurements of the crack in the selected area A, with 621 mm length (Fig. 6a), recorded an average opening of 10 mm, with values between 2.7 mm and 21 mm. These values were obtained every 0.35 mm, in a total of 1774 points. Previously study shows that the accuracy of the method, when applied to a crack width ruler with lines thickness between 0.1 and 4.0 mm, is always less than 10% [3].



(a) (b

Fig. 6. Data acquisition for experimental validation: (a) concrete slab specimen and studied area, A; (b) laser scanning.



(a) (b)

Fig. 7. Identification of the crack by TLS: (a) global intensity map; (b) detail of the intensity map corresponding to the crack.

4. CASE STUDY: IC2 – VIADUCT AT RIO MAIOR AND EN114 AT KM 74+040

Scope and location

The viaduct of IC2 (km 74 + 040), over EN114, is located near the city of Rio Maior, Portugal. The viaduct comprises six spans and has a total length of 224 m and a width of 16.5 m. The longest span has a length of 40 m and the tallest column has a height of 32 m (Figs. 9 and 10). In order to validate the method herein pre- sented, it was applied to the North abutment zone. A laser scan- ning and image acquisition survey were planned.

Laser scanning

The location of the laser stations was planned to minimize the number of surveys and to avoid possible omissions. In fact, for the analysis of the area between the north abutment and column P1, three stations were required (Fig. 11). To be noted that two surveys were carried out from station #1: a first one with the laser in a vertical position, and a second one with the laser horizontally placed (90° tilt), to acquire the geometry of the bottom of the deck (Fig. 12). Station #2 acquired the geometry of the North face of column P1 (Fig. 13). A third station, 12.5 m distant from the concrete wall, with a spatial resolution of 2 mm, enabled to record the detailed geometry of the wall of the North abutment, where a crack was detected (Fig. 14). The survey by laser scanning was also important for geometrical registration of reference targets. This information has subsequently been used to generate the orthoimages for the characterization of cracking by image processing.

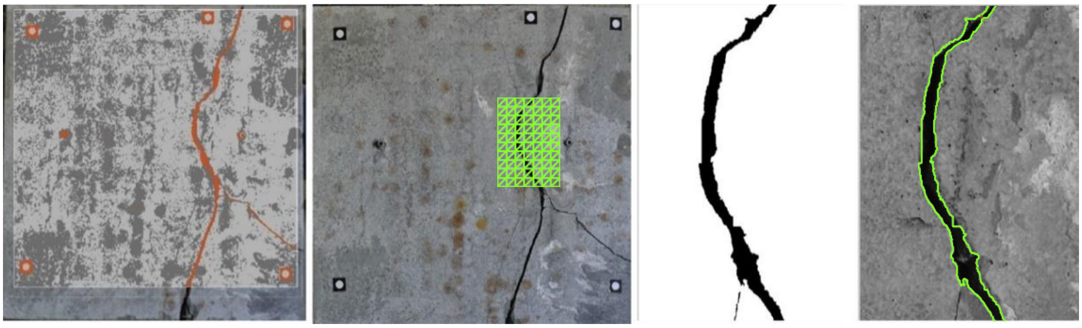

(a) (b) (c) (d)

Fig. 8. Characterization of cracks with image processing: (a) global analysis; (b) discretization of the region of interest; (c) local analysis; (d) definition of the crack boundaries.

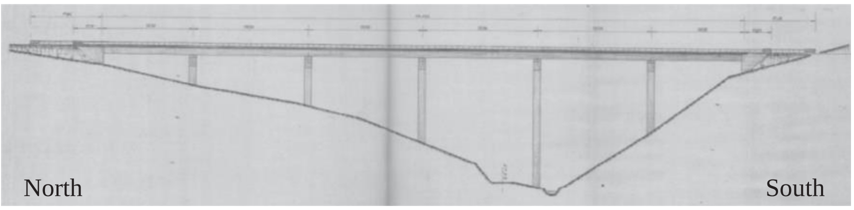


Fig. 9. Viaduct of IC2, over EN114, Rio Maior, Portugal: side view.

Fig. 10. Viaduct of IC2, over EN114, Rio Maior, Portugal: (a) North part; (b) South part.

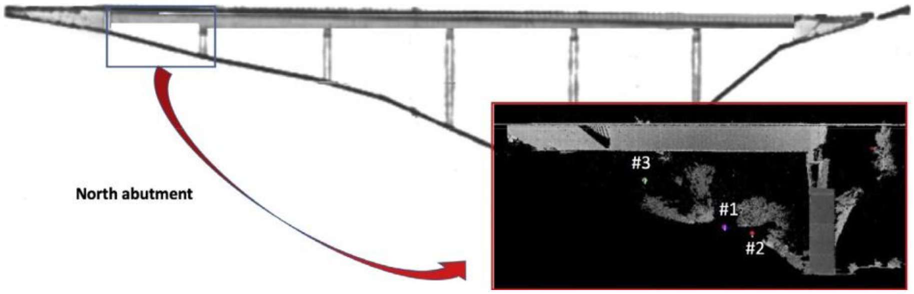


Fig. 11. Location of the stations for Laser scanning.

Image acquisition

The image survey requires access zones for the positioning of photographic stations and, due to the large size of the structure, the use of different focal lengths to survey all key structural members. The north abutment was surveyed with a focal length of 300 mm at 20 m of distance, resulting in a spatial resolution of 0.22 mm/px (Fig. 15).

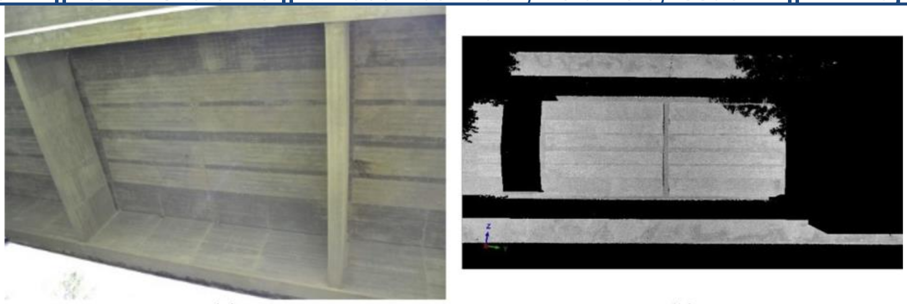
5. IDENTIFICATION AND MEASUREMENT OF CRACKS

Identification

In this particular case, the reference targets selected are the centers of circular holes in the concrete surface (Fig. 14a), probably resulting from shoring of the formwork during the construction process. The coordinates obtained by TLS are later on used for image rectification. As expected, the procedure applied to identify discontinuities by TLS was not effective for the evaluation of cracks in the wall of the North abutment. Due to the reduced resolution of the laser, the procedure could not identify relevant discontinuities, since the laser beams don’t penetrate into the cracks these could not be identified. On the contrary, the global processing of the orthorectified images allowed the identification of the crack in the analyzed area. An unsupervised classification using ISODATA algorithm was applied [20,27]. However, the high density of dirt and moisture stains on the concrete surface can cover some parts of the cracks. In some cases, the stains in the upper area of the crack turned difficult to clearly identify the crack borders (Fig. 16). This occurred regardless of the algorithms used in the multispectral analysis. In these situations, the semi-automatic procedure, aiming at defining crack segments with distinct orientations, was applied: four points (red dots in Fig. 16b) were selected to define the vertical coordinate and thus to define the boundary of five local regions of interest (LROI).

Measurement

After the identification of the crack and computation of the crack’s global parameters, namely location and orientation, a local analysis was performed. In this step a semi-automatic procedure was conducted. After the selection the GROI, the user defines initial points, which coincide with cracks boundary interruption, caused by changes in the orientation of the crack or dirty stains. These points are then used to automatically define the LROIs (red dots in Figs. 16a and 17a). Even with this approaches, in some sections the crack boundaries were difficult to detect by MCrack, due to large dirt and moisture stains. Fig. 17 summarizes the procedure per- formed, indicating, to serve as examples, LROI #2 and #3, being in the first case the crack conveniently identified, whereas in the second some sections of the crack vanished during local processing. The local analysis of the detected cracks allowed its characterization, by measuring width, length and orientation, with a spatial resolution of 0.22 mm/px (Fig. 18).



(a) (b)

Fig. 12. Geometric survey with laser scanning of the lower face of the deck of the second span (N-S) (station #1): (a) photo of the analyzed area; (b) point cloud.

(a) (b)

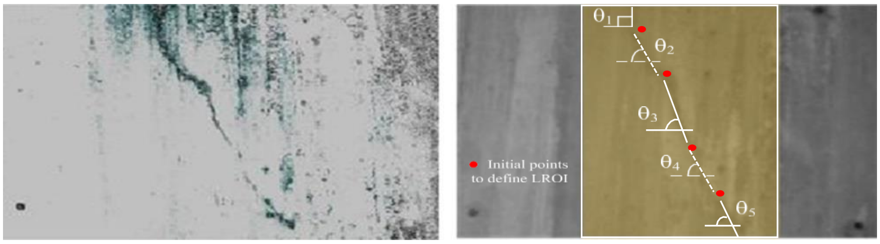
Fig. 13. Geometric survey with laser scanning of the North face of column P1 (station #2): (a) photo of the analyzed area; (b) point cloud.

(a) (b)

Fig. 14. Geometric survey with laser scanning of the wall of the North abutment, East side (station #3): (a) photo of the analyzed area and reference points; (b) point cloud.

(a) (b)

Fig. 15. Details of the north abutment: (a) East view; (b) bottom view.



(a) (b)

Fig. 16. Global processing by multispectral analysis: (a) identification of the crack; (b) critical area and orientation of crack segments.

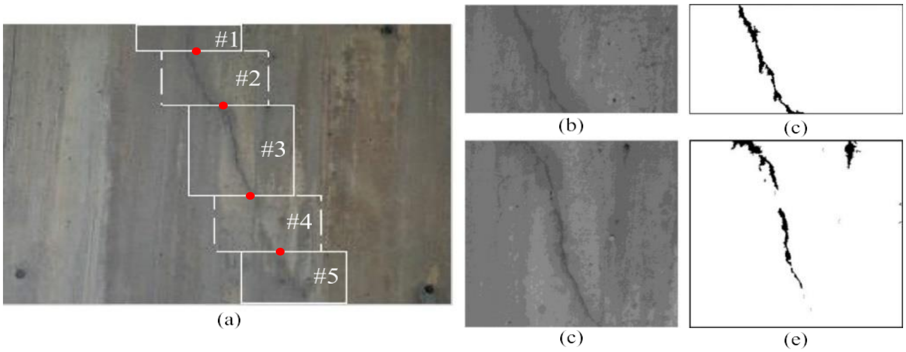
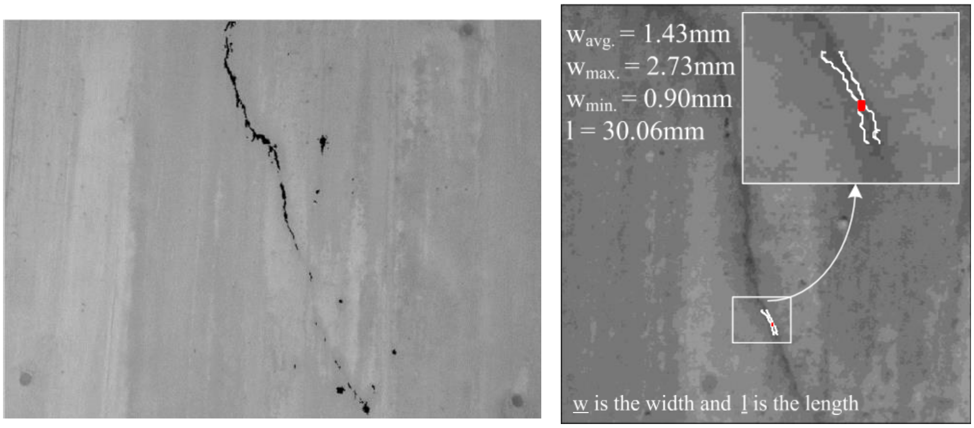


Fig. 17. Local analysis by MCrack-TLS [3]: (a) local regions of interest (LROI); (b) image; (c) final crack pattern of LROI #2; (d) image and (e) final crack pattern of LROI #3.

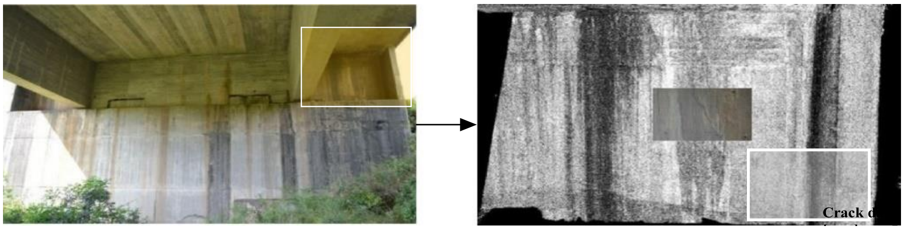


(a) (b)

Fig. 18. Crack characterization: (a) final crack pattern (b) crack measurement performed on a user-made selection region of the LROI #3.

6. OUTPUTS AND RECORDED DATA

For bridge inspectors, besides the acquisition, processing and recording of data, it is decisive to have an easy access to the latter. In this scope, if an exhaustive assessment of the structure had been performed, all images with cracks identified by the method can be uploaded into the 3D model, with all relevant information linked. This 3D model can be later consulted using a user-friendly graphic interface. To serve as example, Fig. 19 shows an image of the identified critical region incorporated in the 3D model obtained by laser scanning, plotting a table with all relevant crack data: average, maximum and minimum width and length.



(a) (b)

Fig. 19. Crack characterization: (a) identified critical region, (b) 3D model with the processed image of the critical region attached, as well as all relevant data.

CONCLUSIONS

This paper presents a first approach of the method 'MCrack- TLS', developed by combining image processing and terrestrial laser scanning, aiming at assessing cracks in concrete bridges. This combination is the major contribution of the method, where: TLS allows a previous and accurate image orthorectification; and image processing the characterization of cracks on concrete surfaces. The overall cracking pattern can be obtained and recorded using this robust and accurate method. The local analysis of the detected cracks allows measuring their width, length and orientation. These features show that the proposed method can be an important aid in the definition and optimization of maintenance interventions of concrete bridges. Compared to traditional methods, the main advantage of MCrack-TLS is the automatic processing of information, resulting in higher speed, efficiency, reliability and both quantity and quality of data. Previously parametric study shows errors up to 10% in the measurement of cracks [3]. In addition, a comprehensive database is created and can be recorded in 3D models. Terrestrial photography requires access for positioning the photographic stations and an exhaustive survey of the structure, which involves the use of various focal lengths to reach the required resolution. The laser scanning proved to be suitable for the geometry survey of structures and build 3D models, including information regarding reference points, essential for crack characterization. Presently, the method is applied to exposed concrete surfaces and presents the following main limitations: (i) the non- operation on surfaces with dirty stains that hide cracks; and (ii) the exhaustive image survey needed to achieve the required resolution. In the first case, the limitation is transverse to all existing methods. In the second case, the use of robotized equipment for image acquisition, such as Unmanned Aerial Vehicle (UAV), represents an attractive and cost-effective tool. However, still presents significant challenges and the definition of proper protocols, in order to ensure the required precision and accuracy of results, is currently under evaluation

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