APPLICATION OF DRONES AND IMAGE PROCESSING FOR BRIDGE INSPECTIONS IN SOUTH AFRICA

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ABSTRACT

In South Africa, visual inspections for all bridge structures are required every five years. A need was identified to establish if it would be practical to utilise technologies, such as drones and photogrammetry, to improve inspections and to reduce the cost of inspections. Drone and photogrammetry technologies are large components in the Fourth Industrial Revolution (4IR). For proof of concept, two bridges were inspected using a drone. The drone inspection data captured for the two bridges was processed and point cloud models were created. These point cloud models were then used to establish whether defects, identified on these bridges previously by way of regular TMH 19 visual assessments, could be identified from the point cloud models. The outcome of the study showed that it would be possible to use processed images from drone inspections or other image capturing methods to inspect bridges and for monitoring purposes. The use of these technologies could improve the inspection methodology, not only of individual structures, but also of a network of structures as required by road authorities. Recommendations are made for future work.

1. INTRODUCTION

1.1 Background

The recommended interval for bridge and culvert inspections in South Africa is 5 years (COTO, 2017). To conduct these visual inspections every 5 years is a challenging task for provincial and municipal road authorities in South Africa. Budget and capacity constraints often lead to inspections not being done or unqualified inspectors being used, resulting in poor quality inspection data. Good quality inspection data that can be entered into a bridge management system is essential to determine maintenance budgets and schedules to protect the structural integrity of a bridge and ensure the safety of road users.

Utilising new technologies, such as drones and photogrammetry, has the potential to improve inspection methodology, improve quality of inspections, lead to cost and time savings, and create a safer environment for inspectors.

A similar study has been conducted by the Minnesota Department of Transport together with industry stakeholders. This three-phased study investigated the use of drones for bridge inspections. The study focussed on rules and regulations, drone hardware and the ability of drones to collect quality inspections data. During the Minnesota study it was noted that drone technology continues to evolve substantially, making it possible to achieve what was previously considered a limitation. The ability of drone technology to conduct bridge inspections was confirmed by the Minnesota study, but the practicality to conduct network inspections of thousands of structures is yet to be determined (Wells & Lovelace, 2018).

The University of Sannio, Department of Engineering, has addressed some of the practical issues on the use of drones for construction inspections. It was noted that from the top industries in the US using drones, only 9% of these industries use drones in construction (structure) application. The need to increase the use of drones in condition assessments of structures was identified (Ciampa, De Vito & Pecce, 2019).

Currently bridges and culverts are inspected using a defects-based system as prescribed in TMH 19. During the visual inspection, defects are identified on the various structural elements and rated in terms of degree (D), extent (E) and relevancy (R). These DER ratings, combined with weights allocated to the different structural elements, are used to calculate a condition index for the structure. The condition index is the Priority Condition Index (PCI), which is then used to categorise the structure as very good, good, fair, poor or critical (COTO, 2017).

The requirements for a person to be accredited as an inspector of road structures are specified by the COTO Structures Sub-Committee and are included in TMH 19. COTO has three grades of inspectors, namely a Senior Bridge Inspector, Bridge Inspector and Culvert Inspector (COTO, 2017).

The qualification and experience requirements for accreditation as a Bridge Inspector are as follows:

- Professional Engineer with a minimum of 5 years bridge and culvert design experience obtained during the last 25 years; or
- Professional Technologist with a minimum of 10 years bridge and culvert design experience obtained during the last 25 years.

1.2 Aim & Scope

The aim of this study is to investigate the practicality of using drones and image processing for bridge inspections. The key considerations for this study are:

- Drone regulation in South Africa;
- Drone licensing requirements;
- Drone operation types;
- Type of drones available;
- Battery life required for the duration of bridge inspection;
- Rotational cameras for under bridge inspection;
- High resolution camera - cost versus sufficient quality;
- Influence of limiting illumination under a bridge;
- Image processing software; and
- Ability to identify defects from processed images.

The main objectives for the use of drones and image processing are to:

- Improve the inspection methodology;
- Improve the quality of inspections; and
- Create a safer environment for inspectors.

The scope of this paper is to present the results of the initial phase of the study, which presents the proof of concept of drone bridge inspections using image processing to establish if these technologies can be adopted for use in the South African context.

2. LEGAL REQUIREMENTS PERTAINING TO THE USE OF DRONES IN SOUTH AFRICA

When considering the use of drones for bridge inspections, it is important to take into account the legal and regulatory requirements pertaining to drone operations in South Africa. Aviation regulations in South Africa for drone operations remain relatively strict compared to other countries.

Operating drones in South Africa are subject to the following rules, unless approved by the SACAA (SACAA, 2017):

1. Drones may not be flown within a 10 km radius of an airport without special permission from the South African Civil Aviation Authority (SACAA);
2. Drones with a mass exceeding 7 kg may not be flown;
3. Drones may not be flown within 50 m of people or private property (without permission from the property owner);
4. Drone pilots must maintain a visual line of sight with their drones at all times while in flight;
5. Drones may only be flown during daylight hours; and
6. According to the SANPARKS website (https://www.sanparks.org/assets/docs/tourism_reservations/park-regulations), "The use of drones inside (or over) national parks is strictly prohibited."

The main limitation for the use of drones for bridge inspections in South Africa is flying within 50 meters of a public road. Permission to operate for the mentioned rules can be granted by the South African Civil Aviation Authority (SACAA) and should be included in the Remotely Piloted Aircraft Systems (RPAS) Operators Certificate (ROC).

Each drone operation requires different licences for approval depending on the type of operation. The different licenses required for the different type of operations are summarised in Table 1 (Kock, 2015).

Table 1: RPAS operations versus required approval

		Type of Operation			
		Commercial	Corporate	Non-profit	Private
Required Approval	Air Service Licence (ASL)	YES	N/A	N/A	N/A
	RPAS Operators Certificate (ROC)	YES	YES	YES	N/A
	RPAS Letter of Approval (RLA)	YES	YES	YES	N/A
	Remote Pilot Licence (RPL)	YES	YES	YES	N/A
	Certificate of Registration (C of R)	YES	YES	YES	N/A

Using drones for bridge inspections requires a commercial licence and includes the followng (SACAA, 2017):

- Air service licence;
- RPAS operators certificate;
- RPAS letter of approval;
- Remote pilot licence;
- Certificate of registration; and
- RPAS maintenance technician.

The process to obtain approval for a specific operation requires the following six steps (SACAA, 2017):

1. Registration of the drone;
2. Letter of approval from the Director of the South African Civil Aviation Authority;
3. Pilot licence;
4. Operators certificate;
5. Submit flight plan detailing the mission; and
6. Permission from landowner.

3. METHODOLOGY

For the proof of concept, two bridges were identified from the Gauteng provincial bridge network. TMH 19 visual assessments of these two bridges were conducted in 2016 and the inspection data for both bridges, including all the identified defects, the DER ratings of these defects, the condition indices (PCI) and inspection and inventory photos, are available. The two bridges were chosen based on their proximity to Pretoria and Cullinan and their location on a road with a low traffic volume. The locations of the two bridge structures are shown in Figure 1. The Gauteng Department of Roads and Transport (GDRT) gave permission as landowner for the drone inspections of the two bridges.

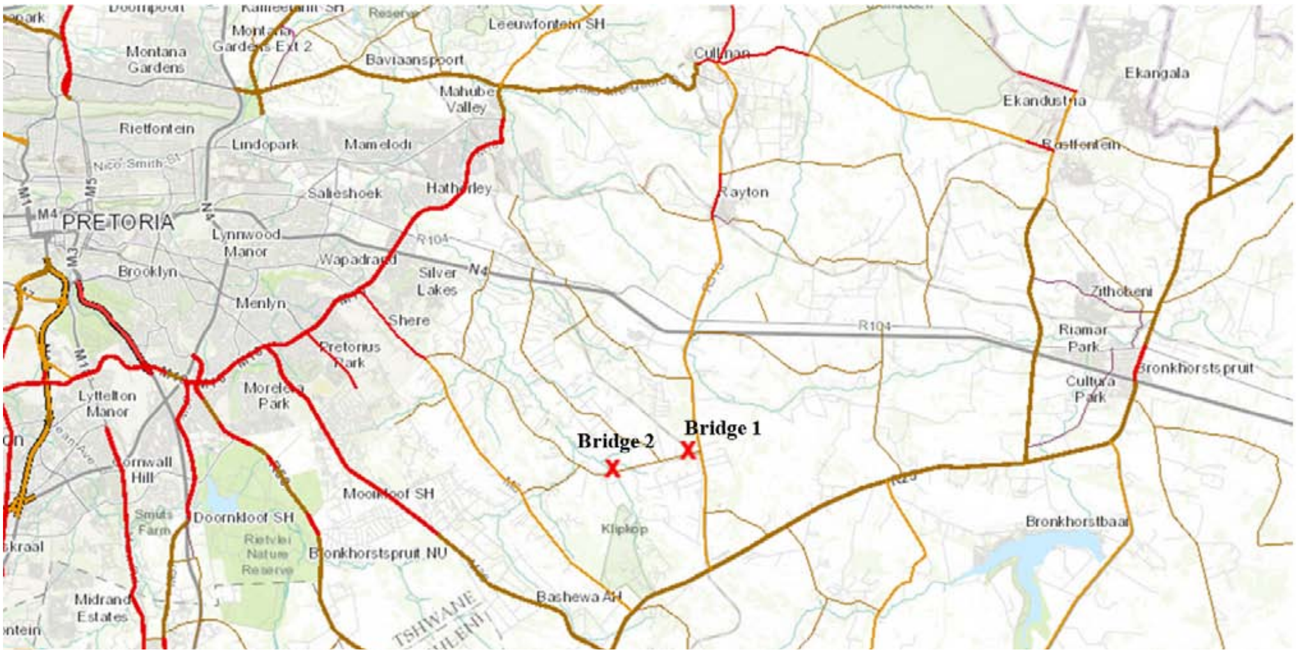

Figure 1: Location of the drone inspected bridges (Gauteng RAMS Geo-spatial Decision Support System)

Staff from the CSIR and an industry partner, Premier Mapping Africa, conducted two visual bridge inspections using drones on 17 February 2020. The inspection data captured for the two bridges with the drone was processed and point cloud models were created for further analysis. The 2016 bridge inspection data for the two bridges was then used to determine if the same defects could be identified using the point cloud model.

Premier Mapping manage aerial survey projects and is licensed to offer aerial survey services using full sized aircraft as well as RPAS (drones). Premier Aviation holds an Air Operator Certificate (AOC) for manned aerial surveys and an ROC for RPAS aerial photography, surveys and industrial inspections.

4. OVERVIEW OF THE 2016 VISUAL BRIDGE INSPECTION INFORMATION

Information for the two bridge structures extracted from the GDRT BMS is provided in Table 2.

Table 2: BMS Information for the two bridges used in the study

Bridge No.	Bridge Name	PCI Value	Condition Category
D631_01N_B4435	Railway bridge	64.3	Fair
D631_01N_B4095	Bosckop River bridge	93.8	Very Good

The defects recorded for the two bridges during the 2016 inspection are shown in Table 3. The railway bridge is in a fair condition, mainly as a result of the abutment seating cracks.

Table 3: Defects identified during 2016 visual inspections

<table>
<tr><th colspan="2">Railway Bridge</th></tr>
<tr><td>
Interlocking blocks missing</td><td>
Abutment seating cracks</td></tr>
<tr><td colspan="2">
Vegetation growing through the interlocking paving on the abutment</td></tr>
</table>

Table 3: Cont'd

River Bridge	
 Waterway debris & vegetation	 Corroded handrails
 Abutment crack	 Spall on pier
 Scuppers too short	 Vegetation on road surface/ hidden guardrail

5. DISCUSSION OF THE DRONE INSPECTIONS

Images of the two bridges were captured using the DJI Inspire2 drone and a Zenmuse x4S camera, mounted on the bottom of the drone. The images captured during the inspections were processed using Pix4D software to create point cloud models. It should be noted that there are free or open source processing applications available, however Pix4D is the preferred software used by Premier Mapping Africa. A desktop i-core 7 with 64 GB SSD and 128 GB RAM computer was required to process the images. The total processing time to create the point cloud models was approximately four hours. An accuracy of 2-4 cm was attained in the generation of point cloud models and average GPS error within one metre for georeferencing.

5.1 Railway Bridge

The first bridge inspected is a three span railway bridge with an overall length of 51 m, overall width of 8 m and maximum height of 7 m. A licenced pilot manually operated the drone to capture aerial images. Images underneath the bridge were captured by walking on the ground using the drone as a manually operated gimbal. The total duration of the bridge inspection was approximately 45 minutes and the battery was swapped after 30 minutes. A combination of 462 images were processed to create a point cloud model of the inspected bridge.

5.2 River Bridge

The second bridge inspected is a three span river bridge with an overall length of 27 m, overall width of 11 m and maximum height of 5 m. The same approach was followed as with the first bridge to capture the images, but vegetation in the river under the bridge prevented the drone pilot to capture images underneath the bridge. The total duration of the bridge inspection was approximately 30 minutes and one battery was used. A combination of 359 images were processed to create a point cloud model of the inspected bridge.

The flight paths and the position of images captured by the drone for the two bridges are shown in Figure 2 and Figure 3.

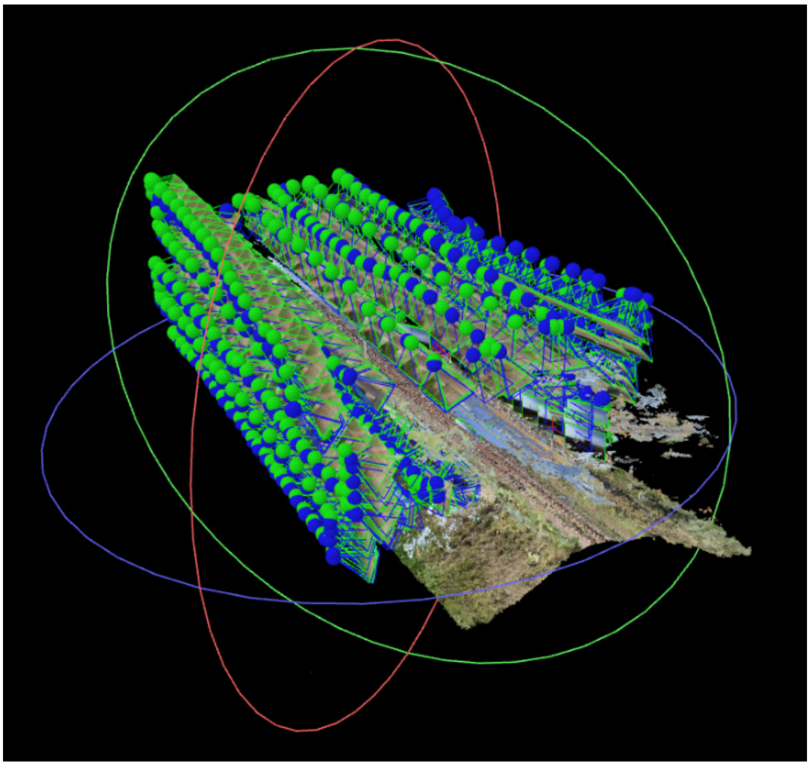

Figure 2: Flight path and the position of images captured by the drone (Railway Bridge)

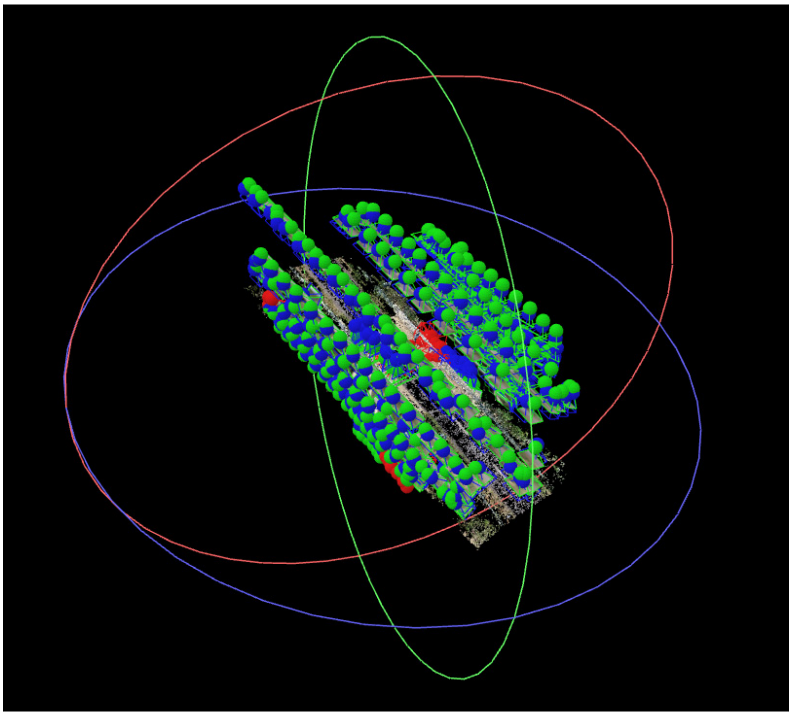

Figure 3: Flight paths and the position of images captured by the drone (River Bridge)

6. RESULTS AND DISCUSSION

The same defects identified during the 2016 visual bridge inspections were investigated using the point cloud models. Point cloud models were created by processing the images captured during the drone inspection and using photogrammetry Pix4D software. It should be noted that there are various photogrammetry software packages available, some of which are free. The study used Pix4D as this was the software used by the company to process the images. The point cloud models for the two structures are shown in Figure 4 and Figure 5.

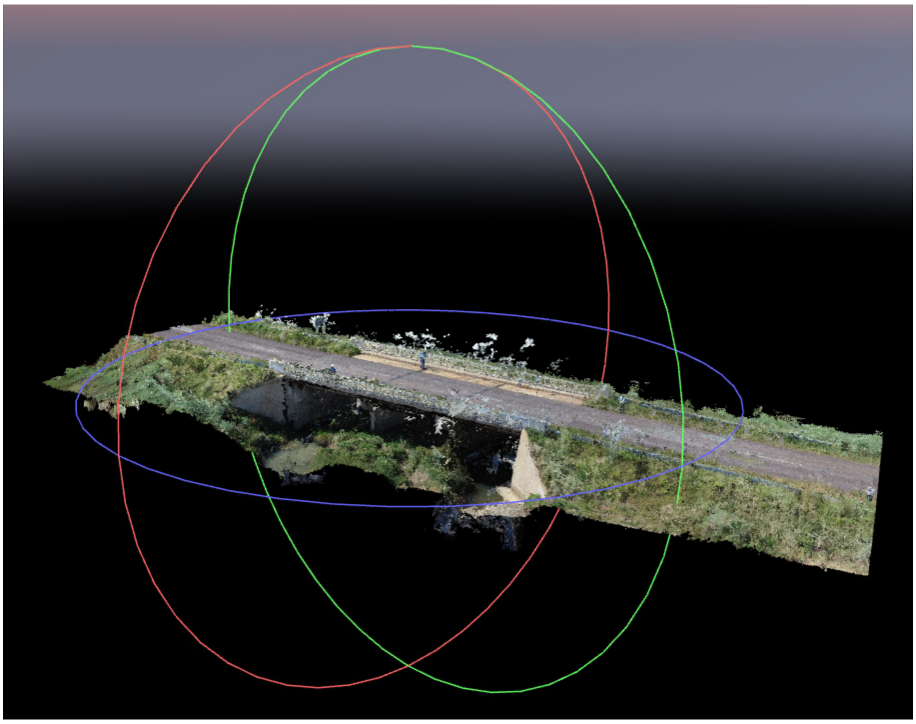

Figure 4: Point cloud model – Rail Bridge

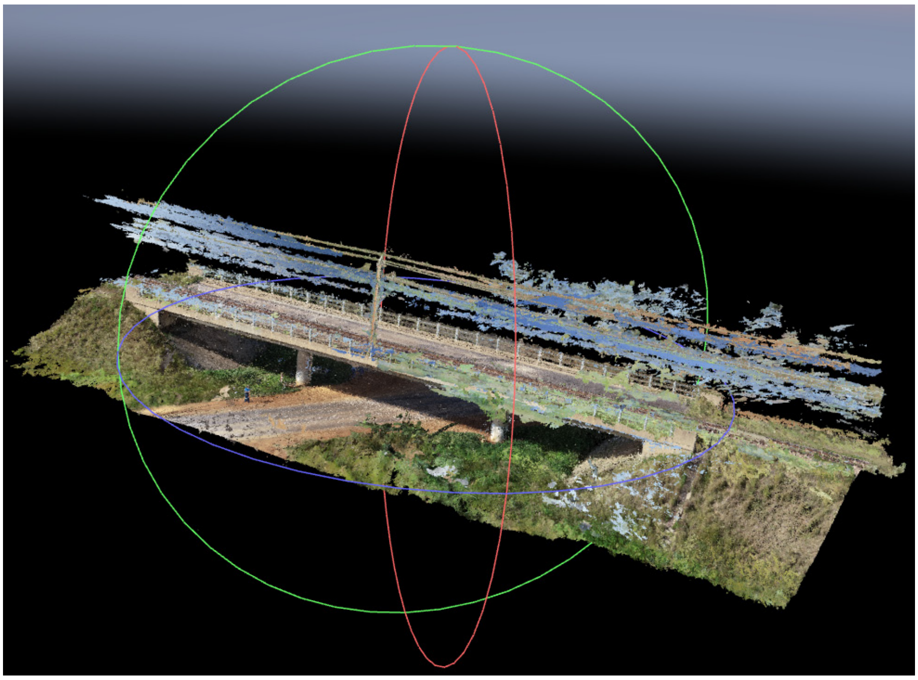

Figure 5: Point Cloud model – River Bridge

Pix4D provides the functionality that enables one to click on any element of the bridge, which then displays all the images from which the selected point is visible. This enables the inspector to investigate the defects from different angles and provides clear images of locations not easily reachable by an inspector.

Each of the defects, listed in the 2016 visual bridge inspection, was investigated on the point cloud model. The following section shows an image of one of the defects on each of the bridges as an example and includes a discussion on the other defects.

6.1 Railway Bridge Defects

6.1.1 Identified Defect: Interlocking Blocks Missing

The missing interlocking blocks are clearly visible on the abutment as seen in Figure 6.

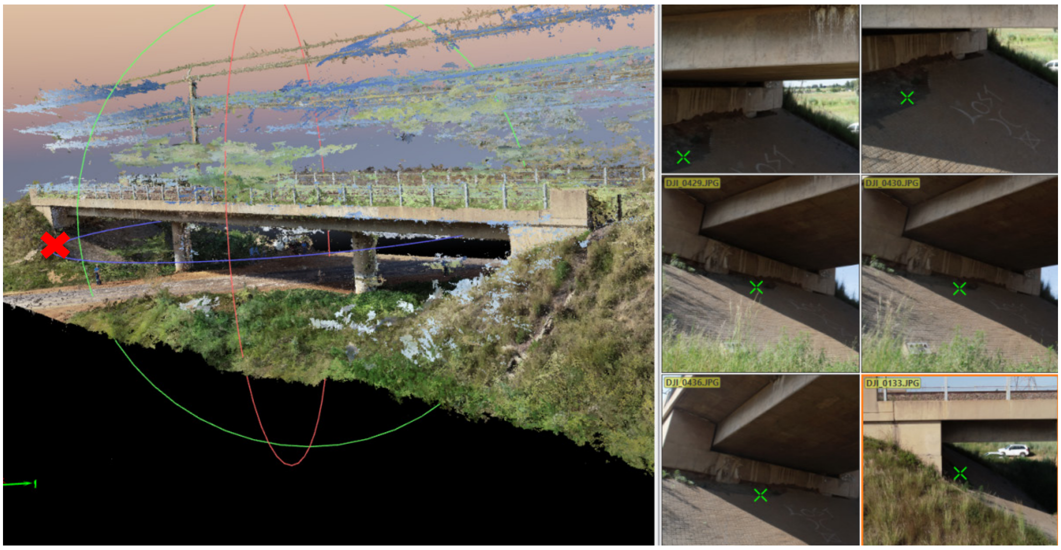

Figure 6: Identified defect: Interlocking blocks missing

6.1.2 Other Defects

Illumination underneath the bridge was limited and the images captured were too dark to identify the abutment-seating crack below the bearing. It appears as if herbicide has been applied to the abutment protection works since 2016, as only slight vegetation growth is visible.

6.2 River Bridge

6.2.1 Identified Defect: Pier Spall

Spalling at the top of the pier is clearly visible as seen in Figure 7.

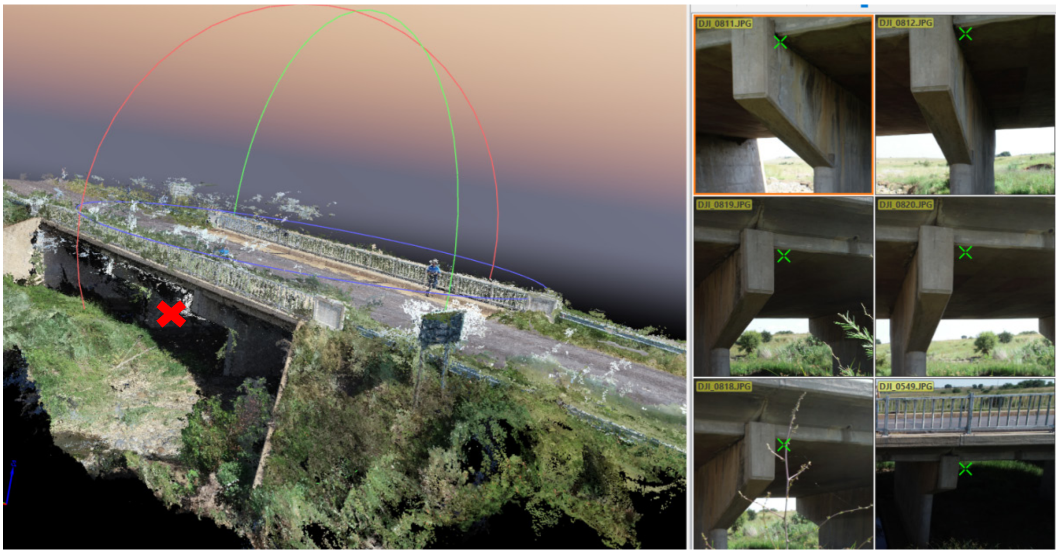

Figure 7: Identified defect: Pier Spall

6.2.2 Other Defects

The illumination underneath the bridge was limited and the images captured were too dark to identify the crack in the abutment wall. The debris and vegetation in the waterway were clearly visible and this prevented the drone pilot to capture images underneath the bridge. It was clear that the scuppers need to be extended and the handrails repainting. Vegetation on the road surface along with the hidden guardrail were also visible.

7. CONCLUSIONS

The initial proof of concept study shows that bridge inspections are possible using drones and photogrammetry. Defects are clearly visible from the photos if sufficient natural illumination is present.

The point cloud model adds context to the defects as a fourth dimension to the DER-rating methodology. Investigating the defects on the point cloud model gives perspective on where the defect is located and provides more information regarding the relevancy of the defect.

Improved photogrammetry software can potentially increase the quality of the point cloud model and could enable inspectors to identify additional defects that would normally not be identified when doing a regular visual assessment. Using higher quality cameras will make it possible to capture images underneath structures where the natural light is low.

The use of drones for network level inspections, as required by provincial and municipal road authorities, will be a challenging task as permission would be required to capture images using drones for large numbers of structures, some located on high volume roads, close to airports or in residential areas. A methodology for network inspections is needed to ensure consistent data capturing and optimised use of technology (cost versus sufficient quality).

Bridge and senior bridge inspectors need to be highly qualified and experienced. Using such individuals to inspect all the bridges and culverts belonging to a road authority is a time consuming and costly exercise. If point cloud models could be used to reduce the number of structures a bridge inspector have to physically inspect on site, the cost of network inspections could be significantly reduced.

It is important to note that drones are only the enabler and that the real value lies in the images that are captured and processed. Drones would be useful when inspecting high structures or over flowing rivers, where it would be difficult for an inspector to reach the entirety of the structure. For lower bridges and culverts with confined spaces, it is not practical to use drones. For such structures, hand gimbals could be used to capture the images and can then be processed using photogrammetry to create the same point cloud models.

8. FUTURE WORK

The focus of the initial proof of concept for using 4IR technologies to improve bridge inspections in South Africa was on the possibility to identify bridge defects using drones and processed images. The two bridges that formed part of this study were visually assessed in 2016. The defects on these bridges and the location of these defects were therefore quantified beforehand.

During the next phase of the study, images of different bridge structures will be captured using drones and hand gimbals. The point cloud models will then be given to an independent, COTO accredited bridge inspector where he/she will attempt to identify defects and rate these using the DER rating methodology using the point cloud models only. The defects identified and the DER ratings allocated to the defects will then be compared with those from previous TMH 19 visual inspections on site. This blind comparison will indicate if it is possible for a bridge inspector to identify and rate defects using point cloud models only, without their presence on site. It will also indicate if additional defects and different types of defects can be identified using the point cloud models. Lastly, it will also provide an indication of the confidence level of the inspector using point cloud models exclusively.

The following aspects will be included for further development in future studies:

- Methodology for network inspections;
- Different imaging technologies, e.g. thermal cameras;
- Inspection of different types of structures;
- The possibility to use the existing database (inspection photos) to assign defects and apply machine learning techniques;
- Integration of point cloud into a BMS; and
- Adjust the layout of inspection sheets and BMS user interfaces to accommodate the image processing inspection methodology.

9. REFERENCES

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