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Automated Infrastructure Inspection based on Digital Twins and Machine Learning

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ABSTRACT: One of the key challenges in our modern society is the provision of safe transport infrastructure. Infrastructure managers are subject to regulations requiring major infrastructures to be periodically checked for damage before it becomes a safety hazard.
In the standard structural inspection, specially qualified civil engineers travel to the object to be inspected on site. Notes, sketches and photos are prepared for the subsequent report. The inspectors are introduced to non-directly accessible locations with special, heavy inspection equipment. During such a test the object is not or only partially usable, which leads to interruptions, delays, traffic jam and thus considerable non-availability costs.
In recent years, approaches of a drone-based structural inspection are increasingly noticeable. These are mainly limited to a visual inspection of the created optical images.
By using new technologies, a more objective and faster structural inspection can be carried out at a lower cost. In order to achieve the highest possible level of automation, the actual test is no longer performed on the real object, but on a digital twin of the construction. The assessment of damages and reporting is carried out automatically.

1 INTRODUCTION

Engineering structures (= civil engineering structures) have to meet requirements with regard to stability, traffic safety and durability. Civil engineering structures are to be subjected to periodic inspection at as even intervals as possible. In this regard, there are laws and regulations in all industrialized countries. For example, in Germany these are the DIN 1076 and the RI-EBW-Prüf and in Austria the RVS series 13.03.XX and the document "06.01.02 Maintenance // Maintenance plan" of ÖBB Infrastruktur AG.
This paper presents the concept and implementation of a pilot project on the use of innovative technologies in the inspection of structures. Service-based support on the basis of unmanned aerial vehicles (UAVs, "drones") and other platforms as well as digital image processing technologies, in particular artificial intelligence methods, should be provided for inspecting civil engineering structures. The aim is to ensure objectified and comprehensible damage detection while minimizing cost-intensive processes (road closures, track locks, underbridge inspection units, etc.).
As a by-product of the application of these technologies and techniques, a digital twin of the particular structure is created, which can be also used for other applications e.g. digitization of the existing structure, As-Built-BIM-models, structure progress control, maintenance planning, etc.

2 USE FOR THE INFRASTRUCTURE MANAGER

In the course of developing a concept for a pilot project, the project participants made fundamental considerations regarding the use of UAVs for the inspection process. The expected advantages of this technology are summarized below.

2.1 Advantages

2.1.1 Data collection

- Fast, secure, and complete capture of objects
- Efficient inspection of hard-to-access structures (such as large viaducts)
- No / minimal operational restrictions during the inspection (at least if there is no need to fly directly above the traffic area)
- Operational restrictions, if required, can be significantly shortened by saving time
- Comprehensive recording and exact localization of structure condition data

2.1.2 Data evaluation

- Automation-based, objectified and comprehensible classification of structure damage
- Location-independent visual assessment of the structure condition by experts based on the aerial survey data
- Geo-referencing of the collected data and position-related evaluation options via temporal change of damaged areas / anomalies etc.
- Safe and semi-automated detection and quantification of condition changes and damage through periodic structural inspection
- Objective and repeatable detection of damage

2.1.3 Data visualization and documentation

- Working basis for client, independent test engineers and fixed asset accounting
- Software independent web-GIS mapping and BIM data delivery
- Structured archiving and retrieval options of existing structure data and structure condition data
- Interface for the integration of planning data
- Use of the three-dimensional structure representation as a planning basis for necessary renovation or maintenance measures
- Easy creation of accurate structure plans from the results
- Unrestricted (or client-definable) group of users
- Data represent the basis for lifecycle management

2.2 Innovation and further development

2.2.1 Data acquisition

The recording of structures with no or minimal impact on the current use is carried out by optical and multispectral sensors in an accuracy sufficient for clear assessments and other planning tasks. Obtained information is combined to form a three-dimensional digital image of the structure using photogrammetric methods. The three-dimensional model forms the basis for further planning tasks.

The information obtained during data collection is better – exactly geo-referenced. All information on the condition of the structure can thus be clearly and continuously assigned to concrete positions. A development assessment of the temporal course of the structure condition is thus possible.

2.2.2 Data evaluation

Image editing and analysis tools are used to automatically determine structure condition information. In addition to visually detectable structural damage (e.g. discoloration, cracks, geometric anomalies that allow inferences on water ingress, moss growth, concrete spalling, sulphate rubbing, etc.), physical material condition data can also be evaluated and interpreted by means of multispectral captured information. An additional compression of location-related structural condition data can be carried out by determined precisely located information by means of further chemical-physical sensors / analyzes.

2.2.3 Data visualization and management

The end product accessible to the client via web-GIS, means software independent, can be integrated as a module into existing structural management databases by infrastructure operators via links, or used as a stand-alone module. An authorization system ensures the control of the availability of information per structure and thus the confidentiality of data.
The start page of the web-GIS allows the client to choose the desired structure, similar to the functionality of Google Maps. By clicking on the structure displayed as an object located on the map, its three-dimensional photorealistic representation is opened and can be zoomed and rotated as desired in three dimensions.
Recorded or automated determined information such as photos and defects can be queried by filter functions (time filter, layer) or by clicking on the corresponding position on the 3D object from the underlying database and evaluated by the expert / commented / categorized (=> tagged). The corresponding information is also stored in the underlying database and can be retrieved in a structured manner using the filter functions.

3 PROJECT GOALS FOR A PILOT PROJECT

A pilot project was carried out in the course of a joint research project with ÖBB. The main objective of this pilot project is to evaluate the extent to which the inspection process at ÖBB can be supported by the use of UAVs on the basis of a real bridge object, the Falkensteinbrücke. In the course of the project the demonstration of the data acquisition takes place by means of UAV.

4 DESCRIPTION OF THE TECHNIQUE AND METHODS USED IN THE PILOT PROJECT

4.1 The drone

A state-of-the-art multicopter is used as the central carrier platform. The selection of the aircraft (payload) is based on the selected on-board sensors (cameras). The flight control of the drone takes place (semi-)automatically or manually dependent on the situation. Compliance with the trajectory according to the flight plan is primarily achieved by using the GPS-RTK and distance sensors. Especially in restricted areas (e.g. bridge underside, between pillars) a stable flight condition is thus ensured with additional pilot monitoring.

4.2 The flight planning and aerial survey

In order to create an accurate 3D model based on photos, it is necessary to obtain photos containing as much information as possible. That is why an accurate flight planning plays a key role.
The flight planning of the bridge aerial survey can be done in two ways – with a previously carried out 3D flight planning or with an on-site flight planning in the field. The choice of the method depends on the available data which differ with regard to the workload. For a 3D flight planning an existing 3D model is necessary. This allows a semi-automation of the aerial survey and the identification of the critical points as well as the take-off and landing places in advance in the office. If a 3D model is not yet available, proceed as follows: first, a manual coarse flight is carried out, then the 3D flight planning is created and finally, the actual measurement flight is completed. In this case, the flight planning must take place in the field. Only like that it is still possible to identify the critical points, as well as the take-off and landing place before the flight.

4.3 The sensors

The central on-board sensor of a drone is a high-resolution system camera for recording in the RGB range. The fixed focal length lens with the highest possible luminous intensity is calibrated before and after use. The RGB camera reproduces everything that the human eye sees. The heterogeneous (natural) light conditions must be taken into consideration, meaning the use of a photo flash or video light and the corresponding implementation in the context of the development work are aimed for. Direct sun and therefore high-contrast shadows can be avoided by planning the flight during a day with slight cloud cover.

4.4 The image processing and evaluation software

A 3D model of the bridge is created based on the recorded images. For this purpose, software for robust photogrammetric evaluation is used. Using algorithms of the bundle adjustment, a precise mutual orientation of the images takes place. This process is supported by the use of pre-geodetically measured control points. In addition, the correct spatial positioning of the object in a superordinate reference system is effected by these control points. The output of the photogrammetric evaluation are 3D-data for the visualization as well as exactly located and corrected images as basis for the detection of concrete damage.
The detection of structure damage in the individual images takes place by using methods of artificial intelligence. For this purpose, fully automated software based on a so-called neural network is used.

4.5 The 3D visualization

On the basis of the data from the aerial survey (point data and aerial photos), with the help of structure condition plans and information about the bridge object from the client, 3D models for the structure visualization are created. The visualizations comprise a) the creation of a photorealistic model from the aerial survey data and b) the creation of a 3D approximation model of the bridge as a BIM model. The provision of the visualizations takes place software independent via web-based viewers. The visualization is retrieved via web-GIS, which serves to locate the project base data. Access to the web-GIS is also software independent via web browser. The web-GIS has an entitlement control that allows sharing data paying attention to different hierarchical levels of an organization. The data can be available to a broad user base by providing them via web services. The user is able to use all functionalities of the web-GIS and the 3D viewer without special software. In addition to the visualization of the test object, the web-GIS can also be used for structured data storage. Besides the localization of the information (photos of damage, test reports...), information can also be filed in a structured way and filterable easily retrieved by the allocation of tags and with the help of a time filter information.

4.6 Detection of concrete damage

The detection of concrete damage takes place on the basis of the onboard sensors images. For this purpose, software for image evaluation and pattern recognition is used. The individual pixels of a photo are divided into different classes due to their absorption and reflection properties. Areas with known spectral properties are marked in advance and then used as a reference. Using deep-learning algorithms based on artificial neural networks, this process can be automated as the number of processed recordings increases.
The detected damages include e.g. discoloration, spalling, exposed reinforcing steel, moss, cracks, deformations, rust marks, etc. In addition to the detection, the exact location of the respective damage is determined. Cracks in the concrete are classified according to their length and width. The selection of the camera is influenced by the smallest crack width to be detected.

4.7 Concrete moisture determination

Concrete moisture is detectable in the near infrared range at a spectral wavelength of about 970 nm. Current own research results with the involvement of Graz University of Technology promise more meaningful values at approx. 1420 nm. Further development work concerning camera, illumination and evaluation are planned: first in the laboratory, then in natural test environment and subsequently on real test objects based on a metrological investigation by a drone.
The determination of concrete moisture with thermal cameras is singular not promising, but as an additional sensor, the use of such systems is conceivable.

4.8 Chloride content determination

Chloride as a cause of damage on concrete structures can be determined on the surface by means of remote sensing methods. First experiments with Graz University of Technology show a spectral imaging of chloride in the range of approx. 1450 nm – similar to the spectral range of the moisture content. An imaging and measurement by means of multispectral sensors is thus possible.

5 THE PILOT PROJECT FALKENSTEINBRÜCKE

The Falkensteinbrücke near Obervellach, with a length of 396 m, is the longest bridge in the ÖBB Tauern Railway and spans an eastern side valley of the Möll Valley via second arches.

For the aerial survey of the Falkensteinbrücke, the northern half of the southern arch was selected; especially the support plate, pillars and bow have been inspected. This corresponds to about a quarter of the entire bridge.
Within the project area, the bridge deck, the arch and the pillars 10-13 were in focus (see Figure 1).

Figure 1. Pillars in the recording area.

The flight took place on 27th of November 2017 in good weather with a hexacopter by the company Skyability GmbH. The control of the drone was done manually by the pilot from the ground, assisted by an observer, as well as by a FPV data link. The distance between bridge and drone averaged 3 to 5 m. The sensors could optionally be mounted on the lower or upper side of the drone to pivot and tilt.

The sensor used was a Sony Alpha 7RII with a 42 MP full frame. The camera was mounted partly above, partly below the drone. The camera was triggered manually by the pilot. The recording positions were chosen in such a way that all surfaces are detected as frontally and diagonally as possible. The overlap of the pictures is about 80%.

For the subsequent geo-referencing of the 3D model, approximately 40 control points on the bridge were geodetically measured in the M31 Land Survey System.

6 DATA EVALUATION AND VISUALIZATION

6.1 3D modeling

To create a photorealistic 3D model of the aerial photographs, a photogrammetric method – Dense Image Matching – is used. The operating principle of the algorithm searches for equal points on several (at least two) images and calculates their coordinates. The result of this process is a point cloud that can later serve as a basis for a BIM or 3D mesh model.

Of the 3599 photos taken, 2919 were selected for modeling and ultimately used. Blurred, too dark or repetitive photos were not used. The first step in modeling is the orientation of the photos. To speed up this process, the GNSS coordinates of the photos of the drones were used. The results of this step provide a "Sparse Point Cloud", improved coordinates and orientation of the photos by calibrating the camera.
In the last step, a dense point cloud was created. With a total of 2919 photos, this process is a major hardware challenge.

6.2 Image analysis

As already mentioned, the image analysis and the damage detection on taken pictures are done with artificial intelligence methods. In the pilot project we used neural networks for this purpose. The further developed software tools are FALCO and IRIS, whereby FALCO is used for the training of the neural network and IRIS for the analysis of a large number of images with the help of a classifier created in FALCO.
All images are examined for different types of damage, such as cracks, spalling, moisture penetration and chloride content. The detected damage is marked on the images (by means of polyline or polygon in a case of a surface damage) and then written to a database. The damage type and the image coordinates of the tag are now saved.
In the next step, the damage entries in the database are geo-referenced with special software.

6.3 Visualization

The so-called web-GIS software was developed for the visualization of the evaluation results. This allows the representation of the 3D model with all detected damage to the model (see Figure 2).
The representation of the damage in the web-GIS takes place dynamically – all data is loaded into a 3D viewer and a table directly from the database, and the changes made by the evaluation team are also saved there. Every defect that has a defined ID is also marked with it.
In the web-GIS there are two views with the data representation – a main view and a detail view. The main view consists of a 3D viewer and a damage list, in which all damages are shown and described. For the assessment, a detailed view was created in which each individual defect is shown with the associated photos and the description.
The results presented in the web-GIS (visualization, tabular list of damages and classification details) will be checked, interpreted and evaluated in the next step by an experienced civil engineer.
The software also has a report generator which supports the editor in the report generation.
The functionality of the web-GIS software allows the evaluation team to access, visualize and process only by means of an internet access, a web browser and login data.

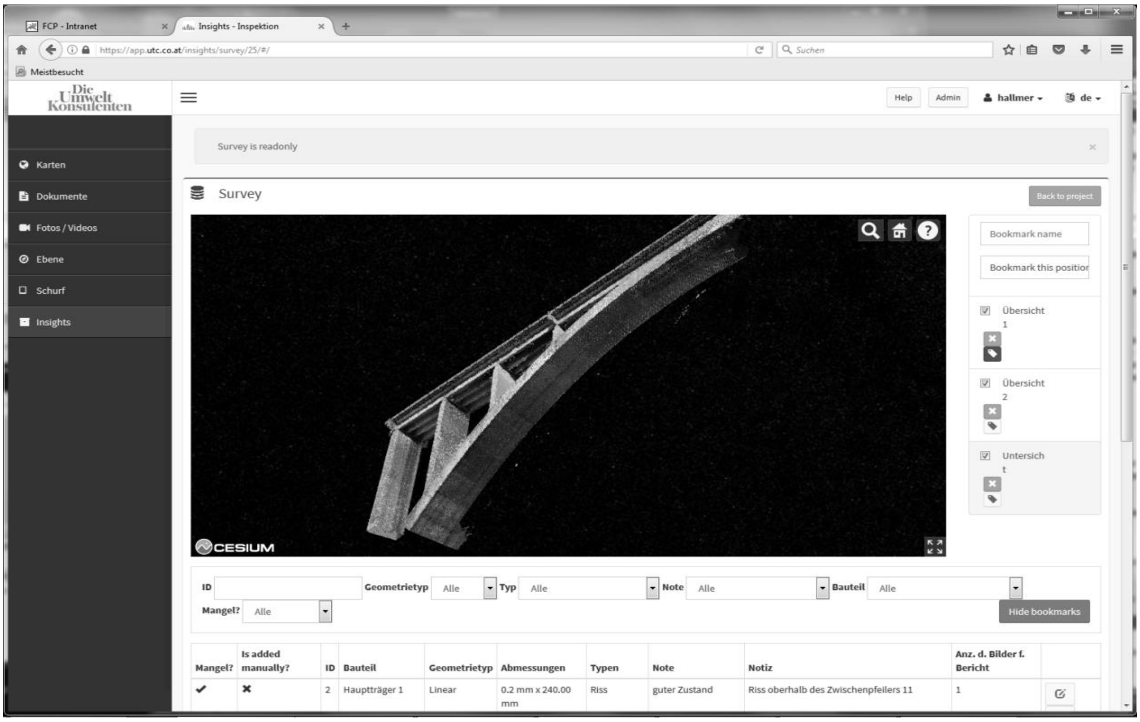

Figure 2. Web-GIS visualization.

7 SUMMARY

In this contribution the potential of new technologies in the field of inspection and condition testing of civil engineering structures is being demonstrated by means of a pilot project. Especially with large objects, such as the mentioned Falkensteinbrücke, where a complete, close-at-hand examination with conventional access technology is not possible or only at very high costs, these technologies can already provide valuable support. At the same time, the unavailability costs due to traffic restrictions can be minimized.
An additional added value can result in the future through the use of additional sensors (multi-spectral cameras, laser scanners etc.) on the carrier platform. Initial tests show potential for surface moisture measurement or determination of chemical surface condition (e.g. chloride content).

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