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A review on computer vision based defect detection and condition assessment of concrete and asphalt civil infrastructure ☆

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A B S T R A C T

To ensure the safety and the serviceability of civil infrastructure it is essential to visually inspect and assess its physical and functional condition. This review paper presents the current state of practice of assessing the visual condition of vertical and horizontal civil infrastructure; in particular of reinforced concrete bridges, precast concrete tunnels, underground concrete pipes, and asphalt pavements. Since the rate of creation and deployment of computer vision methods for civil engineering applications has been exponentially increasing, the main part of the paper presents a comprehensive synthesis of the state of the art in computer vision based defect detection and condition assessment related to concrete and asphalt civil infrastructure. Finally, the current achievements and limitations of existing methods as well as open research challenges are outlined to assist both the civil engineering and the computer science research community in setting an agenda for future research.

1. Introduction

Manual visual inspection is currently the main form of assessing the physical and functional conditions of civil infrastructure at regular intervals in order to ensure the infrastructure still meets its expected service requirements. However, there are still a number of accidents that are related to insufficient inspection and condition assessment. For example, as a result of the collapse of the I-35W Highway Bridge in Minneapolis (Minnesota, USA) in 2007 13 people died, and 145 people were injured [1]. In the final accident report the National Transportation Safety Board identified major safety issues including, besides others, the lack of inspection guidance for conditions of gusset plate distortion; and inadequate use of technologies for accurately assessing the condition of gusset plates on deck truss bridges. A different, less tragic example is the accident of a freight train in the Rebunhama Tunnel in Japan in 1999 that resulted in people losing the trust in the safety and durability of tunnels. According to [2], the failure to detect shear cracks had resulted in five pieces of concrete blocks, as large as several tens of centimeters, which had fallen onto the track causing the train to derail.

In order to prevent these kinds of accidents it is essential to continuously inspect and assess the physical and functional condition of civil infrastructure to ensure its safety and serviceability. Typically, condition assessment procedures are performed manually by certified inspectors and/or structural engineers, either at regular intervals (routine inspection) or after disasters (post-disaster inspection). This process includes the detection of the defects and damage (cracking, spalling, defective joints, corrosion, potholes, etc.) existing on civil infrastructure elements, such as buildings, bridges, tunnels, pipes and roads, and the defects' magnitude (number, width, length, etc.). The visual inspection and assessment results help agencies to predict future conditions, to support investment planning, and to allocate limited maintenance and repair resources, and thus ensure the civil infrastructure still meets its service requirements.

This review paper starts with the description of the current practices of assessing the visual condition of vertical and horizontal civil infrastructure, in particular of reinforced concrete bridges (horizontal: decks, girders, vertical: columns), precast concrete tunnels (horizontal: segmental lining), underground concrete pipes (horizontal) (wastewater infrastructure), and asphalt pavements (horizontal). In order to motivate the potential of computer

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vision, this part focuses on answering the following questions: (1) what are the common visual defects that cause damage to civil infrastructure; (2) what are the typical manual procedures to detect those defects; (3) what are the limitations of manual defect detection; (4) how are the defects measured; and (5) what tools and metrics are used to assess the condition of each infrastructure element.

Due to the availability of low cost, high quality and easy-to-use visual sensing technologies (e.g. digital cameras), the rate of creation and deployment of computer vision methods for civil engineering applications has been exponentially increasing over the last decade. Computer vision modules, for example, are becoming an integral component of modern Structural Health Monitoring (SHM) frameworks [3]. In this regards, the second and largest part of the paper presents a comprehensive synthesis of the state of the art in computer vision based defect detection and condition assessment of civil infrastructure. In this respect, this part explains and tries to categorize several state-of-the-art computer vision methodologies, which are used to automate the process of defect and damage detection. Basically, these methods are built upon common image processing techniques, such as template matching, histogram transforms, background subtraction, filtering, edge and boundary detection, region growing, texture recognition, and so forth. It is shown, how these techniques have been used, tested and evaluated to identify different defect and damage patterns in remote and close-up images of concrete bridges, precast concrete tunnels, underground concrete pipes and asphalt pavements.

The third part summarizes the current achievements and limitations of computer vision for infrastructure condition assessment. Based on that, open research challenges are outlined to assist both the civil engineering and the computer science research community in setting an agenda for future research.

2. State of practice in visual condition assessment

This section presents the state of practice in visual condition assessment of reinforced concrete bridges, precast concrete tunnels, underground concrete pipes and asphalt pavements.

2.1. Reinforced concrete bridges

As per US Federal Highway Administration (FHWA)'s recent bridge element inspection manual [4], during a routine inspection of a reinforced concrete (RC) bridge, it is mandatory to identify, measure (if necessary) and record information related to damage and defects, such as delamination/spall/patched area, exposed rebar, efflorescence/rust staining, cracking, abrasion/wear, distortion, settlement and scouring. While this list of defects comprises the overall list for common RC bridge element categories, such as decks and slabs, railings, superstructure, substructure, culverts and approach ways, not all defects are applicable to all components. Table 1 highlights which defects are applicable to which components and hence need to be checked for each type of component on a bridge. While some of the stated defects are visually detected, some others of them may require physical measurements for accurate documentation and assessment. The size of the defect plays an important factor in deciding if it is necessary to go beyond the visual approach.

In addition to the list of defects stated above, FHWA also mandates that all bearings should be checked during inspection, irrespective of the material type and functional type of the bridge. Some of the relevant defects for bearings are corrosion, connection problems, excessive movement, misalignment, bulging, splitting and tearing, loss of bearing area, and damage. Furthermore, for seals and joints, inspectors focus on a specific set of defects, such as leakage, adhesion loss, seal damage, seal cracking, debris impaction, poor condition of adjacent deck, and metal deterioration or damage. While most of these defects can be detected visually, assessing severity of the defects however needs close-up examination and measurements with suitable tools and equipment.

All of the existing defects on a bridge are categorized on a scale of 1–4 – each corresponding to the condition state of a particular element (1-Good, 2-Fair, 3-Poor, and 4-Severe). The condition state is an implicit function of severity and extent of a defect on a component. Though such categorization of condition states provides uniformity for each component and effects, the actual assessment that results in such categorization can be subjective. Table 2 provides some examples of guidelines provided in [4] for categorization of the condition states of different defects. Please refer to Appendix D2.3 in [4] for the complete list of guidelines for all defects.

There are typically three ways to perform manual inspection for concrete bridge elements: visual, physical and advanced. A combination of these methods is required depending on the condition of the bridge member under consideration. During visual inspection, an inspector focuses on surface deficiencies, such as cracking, spalling, rusting, distortion, misalignment of bearings and excessive deflection. Usually, the inspector can visually detect most of the

Table 1
Defects[a] related to general bridge elements (Grey: Required; White: Not Required) [4].

Element name	Del/Spall	Exp Rebar	Eff/Rust	Crack	Abr/Wr	Distor	Settle	Scour	Damage
Deck									
Top Flange									
Slab									
Bridge Railing									
Closed Web/ Box girder									
Girder Beam									
Stringer									
Arch									
Floor Beam									
Column									
Pier wall									
Abutment									
Pile cap/ Footing									
Pile									
Pier cap									
Culvert									
Approach slab									

[a] Del/Spall – Delamination/Spall/Patched area; Exp Rebar – Exposed Rebar; Eff/Rust – Efflorescence/Rust Staining; Crack – Cracking; Abr/Wr – Abrasion/Wear; Distor – Distortion; Settle – Settlement; Scour – Scouring.

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