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Visual data classification in post-event building reconnaissance

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ABSTRACT

Post-event building reconnaissance teams have a clear mission. These teams of trained professional engineers, academic researchers and graduate students are charged with collecting perishable data to be used for learning from disasters. A tremendous amount of perishable visual data can be generated in just a few days. However, only a small portion of the data collected is annotated and used for scientific purposes due to the tedious and time-consuming processes needed to sift through and analyze them. This crucial process still significantly relies on trained human operators. To distill such information in an efficient manner, we introduce a novel and powerful method for post-disaster evaluation by processing and analyzing big visual data in an autonomous manner. Recent convolutional neural network (CNN) algorithms are implemented to extract visual content of interest automatically from the collected images. Image classification and object detection are incorporated into the procedures to achieve accurate extraction of target contents of interest. As an illustration of the computational technique and its capabilities, collapse classification and spalling detection in concrete structures are demonstrated using a large volume of images gathered from past earthquake disasters.

1. Introduction

After every disaster, a great many images are collected by teams of trained professional engineers, academic researchers and graduate students. The primary functions of a post-disaster reconnaissance team are to collect readily available, perishable data to enable scientific research intended to: (1) learn as much as possible about the nature of the event and extent of the consequences; (2) identify potential gaps in existing research or in the practical application of scientific, economic, engineering or policy knowledge; and (3) make recommendations regarding the need for further investigations, and/or changes to codes, standards and design guidelines. Damaged structures and their components provide critical information regarding performance during the event, and lessons learned from structures that do not experience damage are just as important.

In a typical mission, a group of data collectors is dispatched to a region where an event has taken place. In a well-organized team, information about the local construction, severity of the event, as well as maps of the region are often made available in advance so that planning can take place. The larger group is divided into small teams with at least one more experienced structural engineering evaluator on each team. Each team visits 4–5 (for earthquake) and dozens (for tornado or hurricane) of buildings a day, collecting images at each site and taking measurements from each building. The teams may follow the procedures outlined in established guidelines (e.g. ATC-20 (earthquakes) and ATC-45 (windstorms and floods)) for this process, which is intended for rapid structural evaluation after events (although these teams are not directly rating these buildings) (www.atcouncil.org). Each evening teams return to the base to discuss the findings and to review plans regarding where to spend time and effort collecting data on the next day.

Currently, the primary approach available to researchers for the analysis of such data is tedious and time-consuming manual sorting and analysis of these photographs or videos. Only a small portion of these data, which are collected at great cost, is being used for scientific purposes or decisions in the field. However, automated tools can be developed to aid the structural engineering researcher or the human decision-maker. These tools should provide the analytic power to classify suitable large-scale collections of visual data from disasters in a rapid and efficient manner.

In this paper, our goal is to develop and demonstrate a novel method for the automatic classification of post-disaster images collected during reconnaissance missions. An enabling factor in the proposed method is that we exploit convolutional neural network algorithm (CNNs) implemented for scene (image) classification and object detection to identify and localize target components of interest on the images. Data augmentation techniques that are appropriate for this class of images are developed and described. The parameters in the

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neural network are trained using a large quantity of images so that the resulting trained classifier can achieve robust analysis of the images collected in a disaster, which are typically unordered and complex. We demonstrate this strategy by classifying collapse, and detecting and localizing spalling damage using real-world image data. Once a classifier is developed using this technique, it is applicable to any past or future real-world image data that is visually similar to the data used for training the classifier.

The key contribution of this research is that we provide a feasible solution for automatically analyzing large-scale collections of real-world images from disasters. The past studies reviewed in Section 2 have validated the use of certain techniques (e.g. object detection, damage detection, quantification) using a small quantity of images that were collected with the intention of using them for a particular purpose or application. However, in real circumstances after a disaster, there is no assurance that those techniques will be able to handle large-scale, complex, and unstructured images in such a way as to be tractable. Rather, the proposed method enables accurate and rapid analysis of visual contents in a large volume of real-world images, which will provide support for data collection efforts during reconnaissance missions. Herein, we demonstrate the proposed method using an unprecedented number of real images collected from several previous events. Furthermore, the computational methods developed and validated herein complement past research, and can be coupled with existing methods to incorporate new or existing vision-based damage detection methods for broad application to various situations in a range of disasters. For example, for crack detection, the proposed technique provides images or region of interest on images of target components, which are vulnerable to cracking (e.g. columns or walls after the earthquake).

2. Literature review

In the last few decades, researchers have realized amazing improvements in vision-based structural evaluation for civil engineering applications. These applications span a broad range of studies such as roads, bridges, and buildings. Existing techniques are commonly grouped according to one of the following categories: a given type of structure (e.g. bridge, road, building), damage (e.g. crack, spalling, corrosion), or material (e.g. concrete, steel) [1–3]. However, there are still significant challenges in their implementation, and such techniques often require significant modifications to apply them successfully across many situations even when their application is intended for the same target structure or damage type. Strategies for structural evaluation are often completely different depending on how images are collected and what prior information is available for target areas or damage. We classify the existing techniques according to three different categories.

First, images acquired from a known structure with a stationary background are collected using fixed or highly controlled camera(s). The basic premise for this setup is that damage results in a noticeable visual change in the images. Because the scale of the target areas and their visual contents are quite uniform either spatially and temporally, change detection based on established image processing techniques is often sufficient to detect damage. Applications in this category have considered vision-based monitoring of critical areas [4], railroad damage identification [5], or crack scanning at tunnel [6]. It is possible that damage can be quantitatively evaluated based on prior information including the locations of the cameras, their calibration parameters, and the dimensions of the target structures. Existing image processing techniques that have been developed and used for more traditional machine vision applications (e.g. quality inspection, counting) can be directly applicable for applications in this category.

Second, images acquired from a known structure under varying backgrounds are collected. Typical applications in this category consider periodic vision-based visual inspection using images collected by human inspectors or robotic platforms. Specific applications include pavement cracks [7] or pothole inspection [8], pipeline inspection [9], crack quantification [10], or corrosion detection [11,12]. Images are collected on a regular basis from the same target inspection locations, but significant background variations are present in these images due to environmental noise (e.g. light variation, shadow), color changes (e.g. material degradation, decolonization) or the presence of irrelevant objects (e.g. debris, bugs, and traffic lines) [13]. Thus, damage is not the sole source of visual changes in the images, and false positives are frequently triggered unless strong features of damage can be modeled and extracted, or unless the effects of background variations can be reduced. Regardless of such difficulties, once the inspection techniques and their parameters are calibrated in the early stage, the resulting procedures may be repetitively applied to conduct later inspections with just minor updates. Qualitative and quantitative damage evaluations are thus facilitated based on prior knowledge of the dimensions and location of the target inspection areas [14].

Lastly, images containing unknown buildings/structures are collected. This situation is the most challenging in many respects, and is the one that we address herein for post-disaster evaluation. A major difference from the previous two categories is that image collection processes cannot be optimized in advance for target structure(s) or inspection purposes due to insufficient prior knowledge about the situation and structure. In the literature, a handful of researchers has made contributions to address this field of study due to the complexity involved. Brilakis and co-workers have contributed to the establishment of image-based post-disaster evaluation methods by developing several techniques such as concrete damage evaluation [15], spalling detection [16] or 3D reconstruction using videogrammetry [17]. Recently, Torok et al. developed an image-based 3D reconstruction technique for quantification of cracks and material loss using a structural-from-motion technique [18].

However, there are still several realistic challenges in the evaluation of damage using post-disaster images. A major challenge is faced in processing complex, unordered, and unstructured images because many individuals collect large quantities of valuable images from different regions within a short time. As an example of our experience to be introduced in Section 4, we gathered 90,000 real-world images that were collected during past reconnaissance missions for research purposes. In addition to containing images intended for reconnaissance purposes, such collections also include a significant number of irrelevant (e.g. people, random objects, vehicles) or corrupted (e.g. blurred, noisy, dirt on the camera lens) images. Within these image collections, reconnaissance teams also frequently incorporate metadata in the form of images such as drawings, GPS devices, or measurements (e.g. image of a structural column with a measuring tape). Such diversity in images should be expected during such a mission, as vast amounts of images are collected by dozens of individuals over a short span of time. Taking steps to filter out unnecessary or irrelevant images before classification and detailed analysis can yield drastic improvements in computational speed and outcomes in the end.

Despite such difficulties, two opportunities are enabling automated analysis of such images. First, powerful computer vision methods and machine learning algorithms have been established within computer science and engineering, and related disciplines. Recent CNNs have led to major breakthroughs in image recognition and object detection, and enable the development of high-level abstractions using massive labeled data and parameters [19,20]. They facilitate the development of reliable solutions for object recognition in damage detection applications. Second, we have built a large-scale image database gathered from researchers and practitioners after past natural disasters. In computer vision, image annotation databases have established the foundation for developing robust object recognition techniques through large-scale training and validation. However, the overwhelming majority of these databases target general, everyday objects and images, rather than real world visual data having the complexity encountered with building reconnaissance images. Based on these successful examples, we