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Damage Assessment of Built-Up Areas Via UAS-SfM Derived Point Cloud Data

Mohammad Ebrahim Mohammadi
University of Nebraska - Lincoln, me.m@huskers.unl.edu

Richard L. Wood
University of Nebraska-Lincoln, rwood@unl.edu

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DAMAGE ASSESSMENT OF BUILT-UP AREAS VIA UAS-SFM DERIVED POINT CLOUD DATA

M.E. Mohammadi[1] and R.L. Wood[2]

ABSTRACT

In the aftermath of extreme events (e.g., earthquakes, tsunami, tornados, etc.), rapid and reliable identification of the damage in a built-up area are crucial in to rescue, recovery, and reconstruction operations. While it is critical to conduct efficient emergency response management, lack of classified or tagged damaged regions due to communications and accessibility limitations can further delay recovery operations, rescue efforts, and resource management. Furthermore, critical and perishable damage scenes can also be lost during recovery and cleanup operations immediately following the event. In recent decades, advances in remote sensing technologies demonstrate a great potential to perform rapid reconnaissance and damage assessments. One such technology is an unmanned aerial systems (UAS). UAS platforms require minimal ground support and can be easily and efficiently deployed to collect detailed images from the damaged areas within short duration of time. These images not only depict the current conditions, but can also be used for three-dimensional point cloud reconstructions using a computer vision algorithm, Structure-from-Motion (SfM). Within this study, an algorithm is developed to objectively evaluate SfM point cloud data using local geometric features to detect and identify the locations of damaged structures. This method outlines a rapid, cost-effective, and safe solution for damage assessment of built up areas, which could be used in efficient decision making for emergency response management and estimating the intensity of an earthquake or severity of a tornadic event.

[1]Graduate Student Researcher, Dept. of Civil Engineering, University of Nebraska-Lincoln, Lincoln, NE 68503
[2]Assistant Professor, Dept. of Civil Engineering, University of Nebraska-Lincoln, Lincoln, NE 68503
(email: rwood@unl.edu)

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ABSTRACT

In the aftermath of extreme events (e.g., earthquakes, tsunami, tornados, etc.), rapid and reliable identification of the damage in a built-up area are crucial in to rescue, recovery, and reconstruction operations. While it is critical to conduct efficient emergency response management, lack of classified or tagged damaged regions due to communications and accessibility limitations can further delay recovery operations, rescue efforts, and resource management. Furthermore, critical and perishable damage scenes can also be lost during recovery and cleanup operations immediately following the event. In recent decades, advances in remote sensing technologies demonstrate a great potential to perform rapid reconnaissance and damage assessments. One such technology is an unmanned aerial systems (UAS). UAS platforms require minimal ground support and can be easily and efficiently deployed to collect detailed images from the damaged areas within short duration of time. These images not only depict the current conditions, but can also be used for three-dimensional point cloud reconstructions using a computer vision algorithm, Structure-from-Motion (SfM). Within this study, an algorithm is developed to objectively evaluate SfM point cloud data using local geometric features to detect and identify the locations of damaged structures. This method outlines a rapid, cost-effective, and safe solution for damage assessment of built up areas, which could be used in efficient decision making for emergency response management and estimating the intensity of an earthquake or severity of a tornadic event.

Introduction

As the application of point cloud data in remote sensing workflows becomes widespread in recent decades, multiple techniques have been introduced to acquire these three-dimensional (3D) data including aerial laser scanning (ALS) and aerial photogrammetry. ALS systems utilize light detection and ranging technology (lidar) to collect point cloud data from the region of interest (ROI). Less vulnerable to lighting or weather conditions and highly accurate, ALS platforms require large initial investment and more importantly require a support base close to the targeted surveying site [1]. Contrary to ALS platforms, aerial photogrammetry can be performed through a camera mounted on an UAS. Offering high level of versatility, UAS photogrammetry technique require a lower initial investment and can capture large number of images from the ROI efficiently [2]. The photos collected via UAS then can be further processed to create the point cloud of the ROI via SfM. SfM is a computer vision method to reconstruct a

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[1]Graduate Student Researcher, Dept. of Civil Engineering, University of Nebraska-Lincoln, Lincoln, NE 68503 (email: me.m@huskers.unl.edu)
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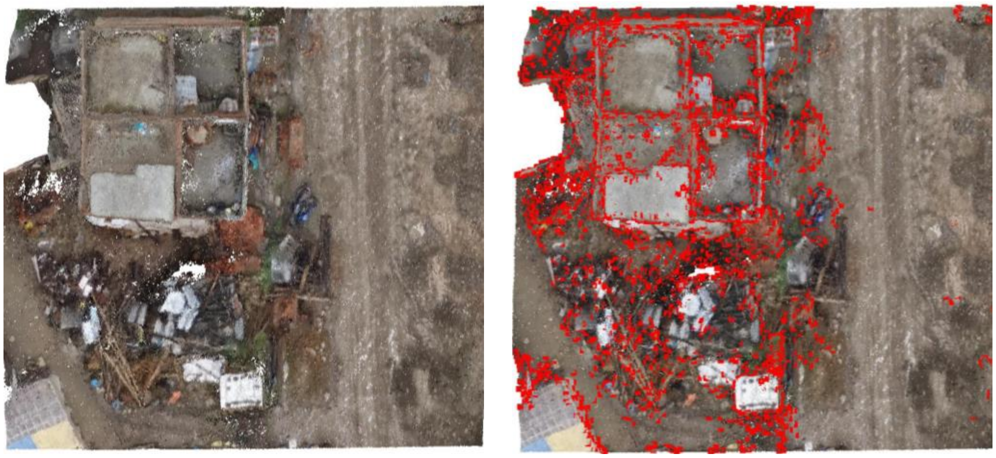
3D scene from series of 2D images [3]. The SfM derived-point cloud data can be created through both open source (e.g., VisualSFM) or commercially available software (e.g., Pix4D, Agisoft). The main disadvantage of SfM derived point cloud data is the lack of real world scale, and their accuracy depends on the ground control method (e.g., georeferencing). However, UAS-SfM derived point cloud data has previously been used for applications in reconstructing scene for structural damage detection [4], and geotechnical assessment [5] due high-level versatility and ease of deployment, data collection efficiency and lower cost of operation. The goal of this manuscript is to introduce a new approach to analyze the UAS-SfM derived point cloud data of large areas after extreme event (e.g., earthquake) to identify the damaged areas, undamaged structures, and roadways and assess the features potential for performing damage assessment of built up areas.

Methodology and Discussion

ASL derived point cloud data has previously been investigated for post-disaster applications. Roher et al. [6] investigates the application detecting and extracting planes through modified RANSAC algorithm and region growing approach from genetically created and ALS point cloud data to detect damaged regions. Furthermore, Yonglin et al. [7] developed a workflow to detect inclined buildings from ALS derived point clouds in the aftermath of natal disasters. The developed workflow initially uses an adaptive RANSAC algorithm to extract building roofs. Then the normal vector of the roof segments, roof geometric axis, and the ground normal vector are identified based on the identified planes in the previous step. Then the angle between geometric axis of the roof and ground normal vector are compared to identify the inclination of structures. While the results of both methods are accurate, both methods rely on ASL data and the well-established RANSAC algorithm, which can be computationally expensive when a dataset of a large area is analyzed (i.e., a point cloud with millions of points).

The developed workflow uses geometrical representation of covariance matrix eigen values and vectors for each point and its selected closest neighboring points to perform the identification task. Within this workflow, initially the input data are down sampled to a uniform spacing of desired level. Then, an algorithm computes the covariance matrix and their corresponding eigen values and vectors for each point. Once eigen value and vectors are computed, four geometric features based on these values are computed including planarity, omni variance, anisotropy and sphericity [8]. Afterward, the probability distribution function (pdf) of each computed feature is learned through Kernel pdf [9]. Afterward, based on the confidence level of 50 percent, the vertices are categorized as likely damage and sharp features and planar areas. In the final step, each points classification is compared, and a point categorized as likely damage or sharp features if and only if all within all features it was considered as likely damage.

To evaluate the developed method, two segments of a UAS-SfM point cloud data are exported as a case study data. The selected point cloud is a reconstructed scene of Bungamati village in the aftermath 2015 Gorkha earthquake [5]. The first case study point cloud data contained a total of 791,628 points and represent various geometries including an intact structure, a damaged area, blocked ally due to debris (in the bottom of the picture) and an open road (Fig. 1a). As Fig 1b demonstrated, the developed method was able to identify the structure perimeter, and highlight the resulted debris of the damaged area. Fig. 2 depicts the second case study point cloud with approximately a total of 1.5 million points. As illustrated in Fig. 2a, the second point cloud contains approximately a total of 10 intact structures, a tree, a water feature, and a few alleys between the structures. The analysis result demonstrated that the developed method was able to detect structures perimeter and distinguish them from the narrow alleys. In addition, other miscellaneous debris across the roadways as well as the tree and the water feature were identified (Fig. 2b).



(a) (b)

Figure 1. The aerial view of the first case study area: (a) RGB colored point cloud and (b) superimposed detected structure and likely damaged areas.

(a) (b)

Figure 2. The aerial view of the second case study area: (a) RGB colored point cloud and (b) superimposed detected structure and likely damaged areas.

Conclusions

This paper introduced a new approach in detecting damaged regions within UAS-SfM point cloud data based on geometrical interpretation of covariance matrix eigen values and vectors. The developed method was able to detect structures perimeter, trees, and debris from the roadway without any height or elevation information. In addition, the method only relays of relative dimensions, and therefore no real-world scale is not needed for the process. The analysis result of this workflow will enable users to assessment damage of built up areas after extreme event through UAV-SfM point cloud data with minimal cost and ground support.

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