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CROWD-SOURCED REMOTE ASSESSMENTS OF REGIONAL-SCALE POST-DISASTER DAMAGE

S. Loos[1], K. Barns[1], G. Bhattacharjee[1], R. Soden[1], B. Herfort[2] , M. Eckle[2], C. Giovando[3] , B. Girardot[3], K. Saito[4] , G. Deierlein[1], A. Kiremidjian[1], J. Baker[1], and D. Lallemant[5]

ABSTRACT

Crowdsourced analysis of satellite and aerial imagery has emerged as a new mechanism to assess post-disaster impact in the past decade. Compared to standard ground-based damage assessments, crowdsourcing initiatives rapidly process extensive data over a large spatial extent, but utilization has been limited due to uncertainty in the results. New methods for crowdsourced satellite-imagery-based damage assessment were assessed through three test approaches. Approach 1 further develops the predominant building-by-building map-based assessment method. Two novel area-based assessment approaches were implemented, where users rate the level of building damage in an image in Approach 2 and compare building damage between two images in Approach 3. Preliminary results from statistical aggregation and regression models indicate that crowdsourced volunteers can visually identify building damage in images on an aggregated, as opposed to building-by-building basis. The correlation between crowd-identified and true damage can be further improved by weighting responses based on user and image characteristics. Results show promise in a novel method of crowdsourcing damage using area-based assessments, which addresses decision-makers' need for aggregated post-disaster loss estimates in a rapid timeframe.

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[1] Dept. of Civil and Environmental Engineering, Stanford University, Stanford, CA (email: sloos@stanford.edu)
[2] Dept. of Geography, Heidelberg University, Heidelberg, Germany
[3] Humanitarian OpenStreetMap Team
[4] The World Bank Group
[5] Earth Observatory of Singapore, Nanyang Technological University, Singapore

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Crowdsourced analysis of satellite and aerial imagery has emerged as a new mechanism to assess post-disaster impact in the past decade. Compared to standard ground-based damage assessments, crowdsourcing initiatives rapidly process extensive data over a large spatial extent, but utilization has been limited due to uncertainty in the results. New methods for crowdsourced satellite-imagery-based damage assessment were assessed through three test approaches. Approach 1 further develops the predominant building-by-building map-based assessment method. Two novel area-based assessment approaches were implemented, where users rate the level of building damage in an image in Approach 2 and compare building damage between two images in Approach 3. Preliminary results from statistical aggregation and regression models indicate that crowdsourced volunteers can visually identify building damage in images on an aggregated, as opposed to building-by-building basis. The correlation between crowd-identified and true damage can be further improved by weighting responses based on user and image characteristics. Results show promise in a novel method of crowdsourcing damage using area-based assessments, which addresses decision-makers' need for aggregated post-disaster loss estimates in a rapid timeframe.

Introduction

After a disaster, reliable evaluation of the scale and spatial distribution of building damage is critical for decision-makers to direct emergency response efforts and effectively allocate international aid. In many contexts, a Post-Disaster Needs Assessment (PDNA) is produced, which requires an informed estimate of physical damage and losses over a large spatial extent to determine the amount of monetary funding necessary for reconstruction and recovery efforts.

In the past decade, crowd-based visual analyses of satellite and aerial imagery have emerged as additional mechanisms to produce estimates of post-disaster building damage. A notable crowdsourced building damage initiative was implemented after the January 2010 Haiti earthquake, in which the Global Earth Observation Catastrophe Assessment Network (GEO-CAN) community of engineers and scientists interpreted building-level damage from very high-resolution imagery [1]. Similar efforts have since been executed in New Zealand and the Philippines, among other places [2, 3]. Crowdsourcing assessments can address decision-maker needs by rapidly estimating damage with extensive spatial coverage. However, utilization has been limited due to inherent uncertainty surrounding the underestimation of damage when observed from above and direct validation of crowdsourced damage estimates with ground-based assessments of individual buildings [2]. Furthermore, through a survey of stakeholder needs, it was found that damage information is required at an aggregate level for many decisions made soon after an earthquake [4]. This study aims to address past crowdsourcing limitations and early post-disaster information needs through three approaches, a building-level and two area-based crowdsourcing approaches, using satellite imagery and ground-based damage assessments from the 2010 Haiti earthquake as testing and benchmarking data [4].

Tested Crowdsourcing Approaches

In collaboration with Humanitarian OpenStreetMap Team and the GIScience Research Group at Heidelberg University, three crowdsourcing approaches were developed using 30 cm resolution satellite imagery collected after the Haiti 2010 earthquake provided by DigitalGlobe. The focus area of interest is approximately 2×4 km, located to the east of Port-au-Prince, and exhibits a wide distribution of building densities and damage levels, as shown in Figure 1a.

Figure 1. (a) Area of interest applied in the crowdsourced assessments in (b) Approach 1: building-level, (c) Approach 2: ranking and (d) Approach 3: comparison tests.

The crowdsourcing Approach 1 is based on previous crowdsourced damage initiatives, in which individual buildings were tagged with a level of damage. This approach was implemented in an OpenStreetMap tasking manager, shown in Fig. 1b, where a user could tag every building within a 125×125 m image. Users could click between pre- and post-event imagery as separate background layers. To avoid errors of omission, nodes are predefined at each building's location. Nodes could be given one of three damage levels: "None", "Some", or "Destroyed", following studies that indicated additional damage levels did not introduce any more accuracy[1, 3].

Since many early post-disaster decisions rely on regional damage information, building-specific data is not necessary, especially considering its uncertainty. Therefore, two alternative area-based approaches, Approach 2 and 3, were tested, where users classified the level of damage in an entire image, rather than at the building level. These approaches were implemented in the crowdsourcing platform, Pybossa, for 125×125 m satellite images, as shown in Figure 1c and Figure 1d. In Approach 2, users are asked to rate on a colored scale of 1-5 the level of damage in an image, with 5 (in red) being the most damaged. In Approach 3, users are asked to select which of two images exhibited greater damage, with the option to select the same damage for both images. In this case, the image to be assessed was iteratively compared to predetermined "anchor images" at 10 levels of known damage until it was placed into a final interval between two anchor images. An additional comparison was made with another random image.

The three approaches implemented multi-pass assessments; a minimum of three users completed each damage assessment task. Training material was developed to guide users through the assessment process and provide examples of damage that is visible from above.

Area-Based Approach Preliminary Results

After an internal testing period, the three approaches were publicized to engage users of varying skill levels. Obtaining a satisfactory number of responses for Approach 1 remains in process, as these tasks are more time-intensive. However, the trials of Approach 2 and 3 are complete and have produced two data-sets for analysis: damage indicator and comparison data.

Crowdsourcing results were validated with ground-based building damage assessments which had damage scales used in ATC-13, where each building is assigned an associated central damage factor (CDF) [5]. Hence, the mean CDF and total number of buildings could be calculated for each image and utilized to validate crowdsourcing responses.

Damage Indicator Results

Damage indicator datasets were obtained from both area-based approaches, where each image has an associated numerical indicator of damage ranging between 1-5 and 1-11 for Approach 2 and 3, respectively. Various regression methods were tested, including linear, multiple linear, polynomial and spline regression. The most straightforward parametric method is single linear regression with the damage indicator as the input factor and mean CDF as the outcome. Initial regression for both approaches exhibits a positive relationship, indicating that the crowd can generally interpret area-based damage.

While the aggregate regression indicates that the overall crowd can identify an image's building damage, individual performance varies widely between users. This suggests the relationship between user responses and true building damage can be improved by detecting characteristics of good and bad performing users and weighting their responses accordingly. Similarly, it was found that users could identify damage better in images with certain visual attributes, such as building density, which implies that results from specific images could be weighted to reflect this. Preliminary cross-validation results show that weighting users by their performance and images by density consistently improves overall damage identification.

Comparing the regression models between user responses and true damage for Approaches 2 and 3, the indicator values from Approach 3 predict lower and higher mean CDF values overall. The regression model for Approach 3 also has a lower mean squared error. These preliminary results are an indication that Approach 3 has greater accuracy over a wider range of true damage. Aggregating multi-pass assessments for an image using statistical methods, such as taking the mean, also exhibit a reduction in the range of residuals between user responses and true damage.

Damage Comparison Results

The damage comparison dataset is a result of each comparison task completed in Approach 3. Network analysis is one method used for analysis, where a network is constructed with each image represented by a node, and each comparison a directed edge between two nodes. Edges are combined and weighted to capture user agreement. The "anchor images" allow sorting to infer the relative order of all images. This approach could be used to dynamically identify images to be prioritized for crowdsourced assessment in a post-disaster scenario.

A Bayesian updating methodology is also implemented to integrate multi-pass assessments. For each image, a prior distribution (defined by a beta distribution) is set over the building damage in the area pictured [6]. With each comparison, the user response and the known damage in the "anchor image" are used to update the posterior building damage distribution. The benefits of this method include quantification of the uncertainty in the assessment of each area and weighting individual user assessments based on their historical performance.

Conclusions

The two area-based approaches demonstrate a methodological shift in executing crowdsourced damage assessments, which inform decision-maker needs for aggregated building damage estimates soon after an earthquake. The ability of the crowd to identify building damage in satellite or aerial images can be improved by weighting certain user and image characteristics in a regression model using a user-provided numerical damage indicator. Network analysis and Bayesian updating are promising methods of sorting comparison data and combining multi-pass assessments. Future work includes benchmarking the performance of the area-based approaches against the building-by-building approach and refining the analysis of each type of results data.

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