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Investigation of rapid remote sensing techniques for forensic wind analyses

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ABSTRACT
Perishable damage data resulting from severe windstorms require efficient and rapid field collection techniques. Such datasets permit forensic damage investigations and characterization of civil infrastructure. Ultimately, observed structural damage serves as a proxy approach to estimate wind speeds for storms that include hurricanes, tornadoes, straight-line winds, etc. One of the more common methods to collect, preserve, and reconstruct three-dimensional damage scenes is the use of an unmanned aerial system (UAS), commonly known as a drone. Onboard photographic payloads permit scene reconstruction via structure-from-motion; however, such approaches often require direct site access and survey points for accurate results, which limit its efficiency. In this presentation, the use of UAS platforms with and without surveyed ground control points is investigated to understand the accuracy if site access is not possible. UAS datasets will be compared to lidar data of various structures collected following the 2017 Hurricane Harvey near Rockport, TX.

Keywords: unmanned aerial systems, structure-from-motion, remote sensing, forensic investigation, lidar

1. INTRODUCTION

1.1. Hurricane Harvey

Hurricane Harvey made landfall on the Texas Gulf Coast on August 25th as a category 4 hurricane with winds of 215 km/hr (Oldenborgh et al., 2017). The event affected many coastal communities including Aransas County, Houston, and other areas; resulting in many injuries, financial losses, and damaged civil infrastructure. Following the event, National Science Foundation (NSF) organized various reconnaissance teams to document and investigate the infrastructure damage. As a result, a team consisted of researchers of University of Nebraska-Lincoln and West Texas A&M University visited the affected areas within Aransas County and carried out deploying multiplatform data collection via various remote sensing platforms including aerial and ground-based surveys.

1.2. Unmanned Aerial System (UAS)

Point cloud datasets were collected following the aftermath of the storm to provide detailed record for forensic investigations. To perform this task quickly, unmanned aerial system (UAS) based photogrammetric surveys are an optimal option, particularly given their overhead view of

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structural damage above the roof level of various structures. UAS data acquisition includes digital images and georeferencing information that can produce a point cloud using an advanced computer vision technique, known as structure-from-motion (SfM). SfM uses a series of two-dimensional images with sufficient overlap to estimate 3D reconstructed scene. Given its efficiency, accuracy, density, and lower-cost (in comparison to fixed-wing surveys), UAS point cloud data acquisition has been widely applied to the areas of transportation, geology, surveying, etc.

1.3. Research Motivation

The authors were equipped with lidar scanners and a UAS for data collection (Kijewski-Correa et al., 2018). For many structures with inaccessibility, UAS is an efficient, accurate and economical approach for data acquisition. This approach does not require reference targets as points of interest can be detected automatically during the point cloud generation. However, the objects dimensions will require scaling to real world units. UAS-based SfM point cloud quality is also dependent on the quality of images. Despite this minor disadvantage, SfM is a rapid and efficient approach for point cloud data collection.

2. PREVIOUS WORK

UASs have been deployed for structural assessments and health monitoring applications for numerous years. This aligns with the increased digital revolution of UAS technology and recently relaxed federal guidelines (FAA, 2016). This literature survey only briefs discusses a few selected applications to demonstrate its development in recent years.

Adams et al. (2013) investigated the application of UASs in a post-disaster assessment at neighborhood and individual building scales after 2012 northern Alabama EF-3 tornado outbreak. The study presented a UAS survey of two severely damaged residential buildings as a case study and reported that the team was able to collect images with ground sampling distance of 2 mm through very-low altitude flights and an onboard 12 MP camera. In addition, Adams et al. (2013) were able to observe and identify roof damage and specific building material in the debris field as well as performing quantitative analyses after stereo-photogrammetric analysis. Similarly, Morgenthal and Hallermann (2014) studied UAS applications in visual inspection of civil structures and highlight the possible applications of these platforms to generate a detailed set of images for any hard-to-reach or critical components efficiently. However, similar to Adams et al. (2013), the study has observed that these platforms are vulnerable to environmental effects (e.g., wind gusts) that can affect the image quality. To address these drawbacks, Morgenthal and Hallermann (2014) introduced a damage detection framework that reduces these adverse environmental conditions using a set of parameters. More recently, Ham et al. (2016) reviewed the potential application of UASs to automate various tasks in construction monitoring and civil infrastructure assessments. The study reported that while the UASs with various onboard sensors have been proved to be an efficient data collection platform; however, there are several knowledge gaps to reach the fully automated workflows in terms of data collection procedures, analyses (e.g., damage detection), and data visualization methods.

In addition to analyze UAS captured images to for damage detection and documentation, these images have been used to reconstruct the 3D scene for structural assessment applications. Galarreta and Gerke (2015) used high resolution oblique images collected by a UAS platform to create a 3D point cloud of a scene. Furthermore, the study combined the 3D point cloud data with results of a developed image analysis technique for building damage assessment. To detect damage in facade and roof components, an object-based image analysis method was developed that uses image segmentation and object classification and this method was supplemented by a user input. Galarreta and Gerke (2015) concluded that while the oblique images collected by a UAS platform are suitable for assessments of façade and roof components, their proposed damage detection method was not able to identify all existing damage patterns and further investigation needs to be performed. More recently, Womble et al. (2017) performed a multiplatform remote sensing survey of industrial structures sustained moderate to severe damage during 2015 Tornado outbreak in Pampa, TX. The collection survey was performed through deploying a ground based light detection and raging (lidar) scanner and a UAS collecting a series of oblique images from damaged structures. This approach enabled the team to create capture affected areas including damaged structures and related debris fields and allows more comprehensive damage analysis to validate new wind-damage prediction models and other predictive damage modeling.

3. METHODOLOGY & APPLICATION

3.1. Data Collection

In this case study, two Texas structures are selected for evaluation: Veterans of Foreign Wars (VFW) building in Rockport and Aransas Pass storage unit facility. VFW is a single-story structure facility, however, most of the roof and walls were collapsed as it was not occupiable. Aransas Pass storage unit consists of multiple single-story light-gauge steel structures in a long rectangular shape. Several storage spaces were intact following the hurricane. Minor damage on the doors can be observed during the visit, as well as complete collapse of a few units. Both lidar and UAS data collection were conducted of the sites to understand and compute the residual structural deformations. These sites are selected for comparisons given their differences in size and geometry, which has an impact when compiling SfM-derived point clouds.

3.1.1 UAS data collection

The available equipment for the aerial surveys was a DJI Inspire 2 UAS with an onboard Zenmuse X5 camera and mounted 15 mm lens. Flight paths were autonomously controlled with the Pix4dcapture application on a handheld android-based tablet, using perpendicular "lawn-mower" like passes due to the various changes in height in the scenes (Figure 1). At Rockport VFW, three flights were performed with an 85% overlap at an above-ground-level (AGL) altitude of 25 meters. Similarly, two flights were conducted at the Aransas Pass Storage Center with 85% overlap and an AGL altitude of 28 meters. This produced a total of 302 and 639 images, for the VFW and storage center locations. The resultant ground sampling distance was between 0.55 – 0.61 cm. Ground control points (GCP) were well distributed to scale the SfM resultant point cloud.

3.1.2. Lidar data collection

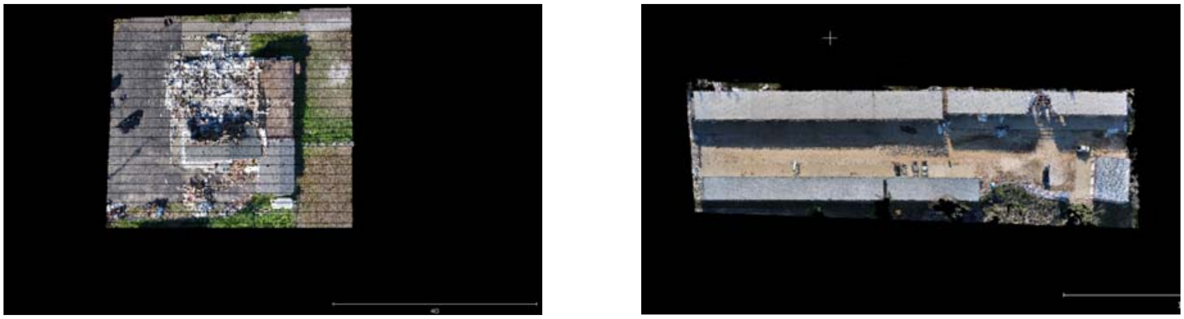
Meanwhile, six lidar scans were obtained at Rockport VFW and sixteen scans at Aransas Pass storage, deployed by Faro Focus 3D S350 and X330 lidar scanners, with a scan resolution of 1/4 and quality or oversampling of 4x. For lidar scanners, multiple scans are often required for manageable point-to-point spacings due to the increasing angular increment as the lidar waveforms diverge as a function of increasing distance from the lidar scanner. Consequently, the VFW and storage facility lidar point clouds were registered using initially natural targets and then via a cloud-to-cloud optimization for a mean error of 0.17 cm and 0.47 cm, respectively.

(a) (b)

Figure 1. VFW flight details: (a) image locations in red and (b) GCPs shown in green

3.2. Data Processing

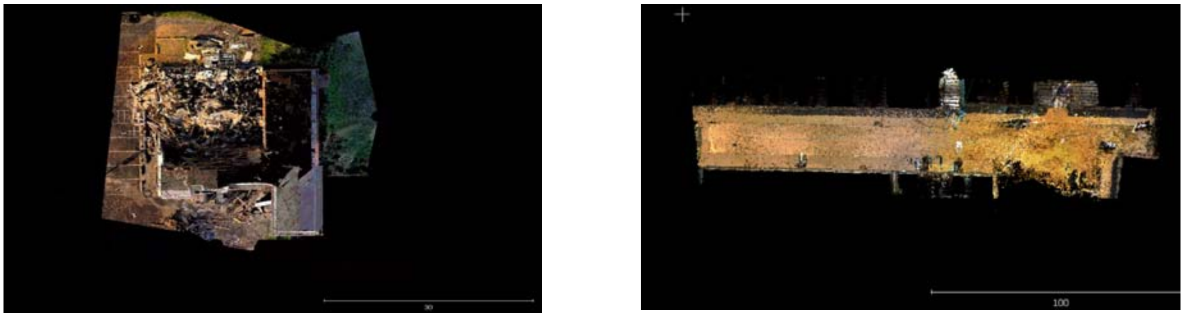
Pix4d is a commercial software commonly utilized for UAS processing, which utilizes high resolution images and form them to produce accurate deliverables, including digital models, point clouds, etc. The processing template for data processing is selected as 3D maps, image scale at one-half, point density of optimal, and the minimum number of matches of 3. The SfM point clouds of Rockport VFW and Aransas Pass storage are displayed in Figure 2. The total number of points in each cloud are 143 and 460 million, respectively.



(a) (b)

Figure 2. SfM derived point clouds: (a) VFW and (b) Aransas Pass storage facility

To georeference the collected data, GPS coordinates of selected checkerboard targets collected by a real-time kinematic (RTK) survey were imported as ground control point (GCP) prior point cloud processing into the Pix4D software to constrain and reduce the point cloud uncertainty. Five well-distributed GCPs including longitude, altitude and elevation were input. These points are constrained by a surveyed-in base station location, which is not tied to a known survey monument location. Furthermore, the GCPs and a few natural targets were utilized as references for lidar scan registration. Lidar point cloud at both sites are shown in Figure 3, identifying that the clouds are ideally consistent and dense. The ground control data will be utilized as both check points (CP), which the model does not consider, and GCPs.



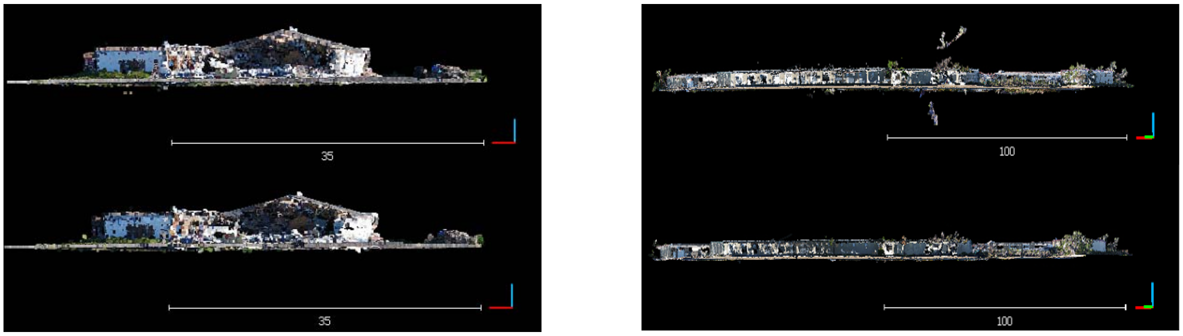
(a) (b)

Figure 3. Lidar derived point clouds: (a) VFW and (b) Aransas Pass storage facility

3.3. Data Comparison

3.3.1 Visual – side view

As can be observed in Figure 4a, the SfM point cloud without GCPs contains a few extraneous points floating next to the structure (on the left side). Also, the ground levels flatness varies slightly differently. The difference is more significant in Aransas Pass storage showing in Figure 4b. Some ground level data are improperly constrained located and floating above the structure. However, the dataset with GCP inputs contains less noise and is more consistent in density and in elevation.

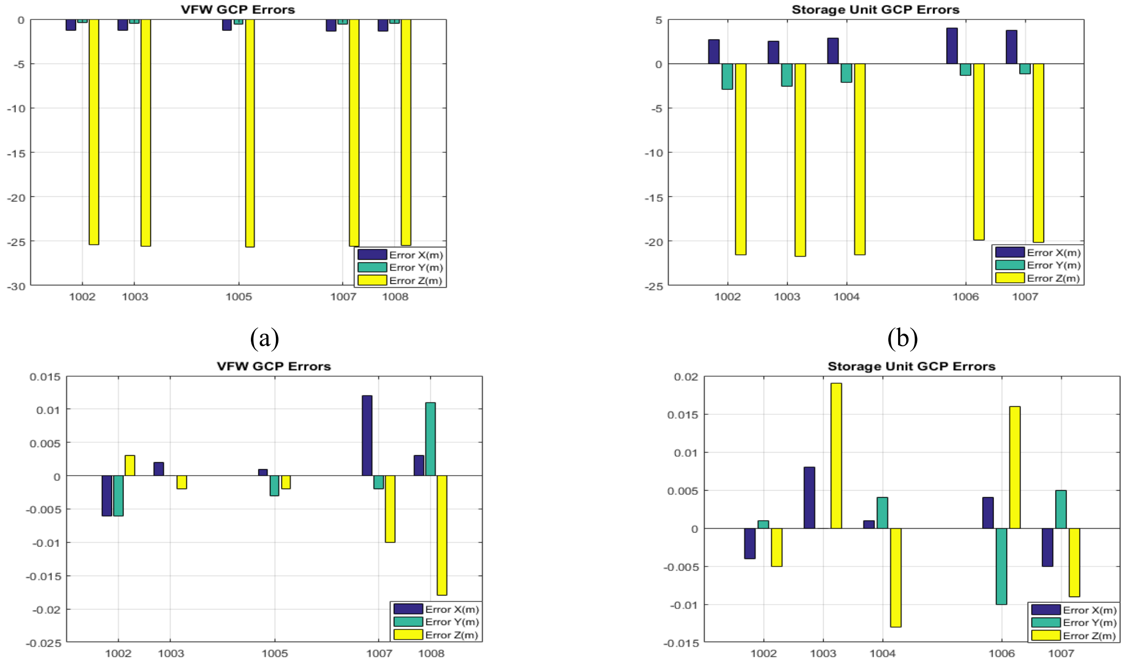


(a) (b)

Figure 4. Side view of SfM point clouds: (a) VFW and (b) storage facility. The top view is shown without GCPs and the bottom view is with GCPs.

3.3.2 Errors at GCP locations

An examination of the checkerboard targets can detail the errors associated throughout the 3D SfM reconstructions. When the processing method does not consider ground control support, the errors at each checkboard had errors of several meters, in various directions, as shown in Figure 5. These targets are categorized as "checkpoints" (CP). High vertical errors are associated with the surveyed-in base station coordinates, which are not constrained to a known survey monument. While these are high in magnitude, the local differences from the median demonstrate a vertical break in the dataset for the storage unit facility due to its corridor-like geometry (of a value of 8.5 m). In comparison, when the RTK surveyed points are included, the errors and the associated vertical break in the storage facility are reduced substantially. This equates to the mean of 0.06 cm in X, 0.02 cm in Y, and 0.1 cm in Z directions. However, an assessment of the GCPs, which the point cloud reconstruction is adjusted to match, is not a robust comparison of the distributed accuracy throughout the clouds.



(a) (b)

(c) (d)

Figure 5. CP errors for (a) VFW and (b) storage facility unit. GCP errors for (a) VFW and (b) storage facility unit

3.3.3 Cloud-to-cloud comparison

The checkerboards and the surveyed GCP locations provide discrete measurements of errors distributed throughout the point clouds. However, the error and noise in the SfM construction are known to vary throughout the point cloud (Wood and Mohammadi, 2015). To compute the differences relative to the lidar point clouds, a cloud-to-cloud (C2C) distance evaluation is evaluated within CloudCompare (CloudCompare, 2014). In this comparison, the lidar datasets are assumed to be the baseline dataset, given their low mean registration values. In Figure 6, most points of structures are at cm level, except at the higher elevations occluded in the lidar point cloud coverage. The results in Figure 7 are substantial that the distance of structure edge is approaching 10 m, due to the occlusion of the lidar point clouds (since only interior access was provided). When using GCPs, the interior located c2c errors were reduced to the centimeter level.

3.3.4 Cross-section view with dimensions

To quickly assess take-off dimensions differences between point clouds quantitatively, a measurement of components between lidar and SfM points clouds was conducted. This was done for the longest wall on the southside of the VFW building as well as the length of the storage facility. Manually extracted measures were approximately 31 and 186 meters for each site, respectively, with details from each point cloud shown in Table 1. The differences between SfM without and with GCPs was shown to be 0.923% and 0.096% for the VFW, as well as 1.773% and 0.107% for the storage facility. The storage facility has greater difference for it is a relatively large structure and the point clouds consists of more points. It can be concluded that the errors may propagate with the increase size of the structure. It is noted that the GCPs reduced the take-off dimension error by a factor of 10 to a value of 0.1%.

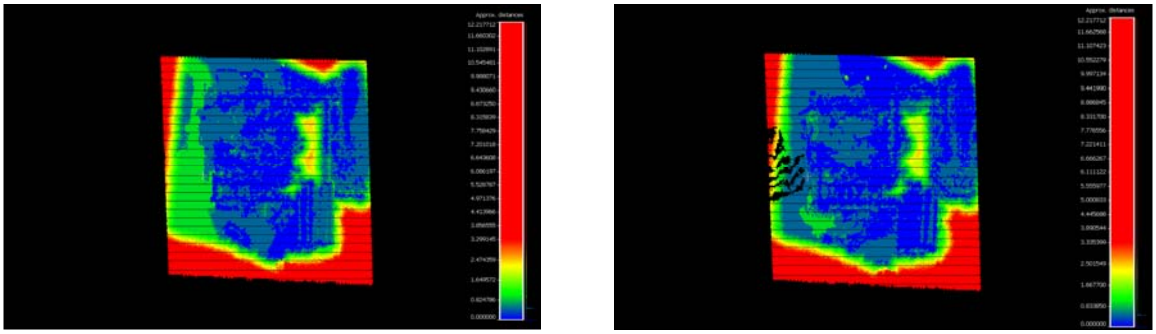

(a) (b)

Figure 6. VFW cloud-to-cloud comparison: (a) without GCPs and (b) with GCPs (units in meters)

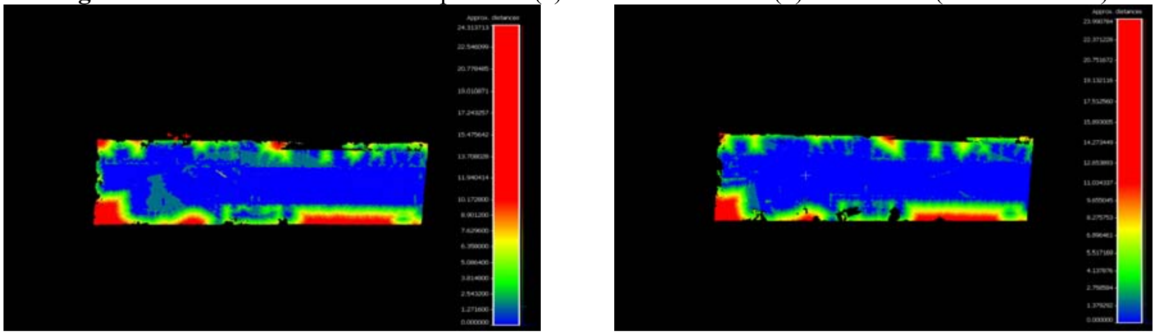

(a) (b)

Figure 7. Storage unit cloud-to-cloud comparison: (a) without GCPs and (b) with GCPs (units in meters)

Table 1 . Dimensions extracted from the point clouds

Location	Lidar (m)	w/o GCP (m)	with GCP (m)	w/o GCP (%)	with GCP (%)
VFW building	31.41	31.12	31.44	0.923	0.096
storage facility	186.08	189.38	186.28	1.773	0.107

4. CONCLUSIONS

UAS point cloud collection is efficient, requires less manpower than traditional methods, and less on inspector/human bias. This study investigates the comparison of SfM point cloud via UAS acquisition with and without GCPs, as well as the accuracy between SfM and lidar point clouds. This is done because of the increased usage of UAS for post-disaster deployments; however, often without ground control support. When examining discrete ground control targets, when ground control was neglected errors were introduced to nearly over several meters, while this dropped to the centimeter level when ground control was included in the processing workflow. When comparing the take-off quantity, the percentage error between lidar and SfM with GCPs are more than ten-times less than that of SfM without ground control. This corresponds to nearly 1.0% error without ground control for these structures, which may be small for certain analyses. However, ground control significantly reduced the error to approximately 0.1%. Consequently, it is recommended that for most structures, especially large areas with various changes in elevations or a long and narrow site (like a corridor), to include ground control to minimize errors. The onboard consumer grade GPS platforms in common off-the-shelf UAS platforms do not provide reliable measurements and their corresponding errors can be unpredictable in nature. UAS surveys for point cloud reconstructions have demonstrated efficient data collection with acceptable measurements when ground control is included. This type of data is extremely valuable for larger datasets or inaccessible areas, particularly in the aftermath of natural disasters given various time restrictions for assessment.

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REFERENCES

Adams, S. M., Marc, L.L. and Carol, J.F., 2013. High resolution imagery collection utilizing unmanned aerial vehicles (UAVs) for post-disaster studies. in Proceedings of Advances in Hurricane Engineering: Learning from Our Past, ATC & SEI Conference on Advances in Hurricane Engineering 2012, Miami, FL. pp. 777-793.

CloudCompare, 2014. CloudCompare Version 2.6.1- User Manual, <https:www.cloudcompare.org>

Kijewski-Correa, T., Gong, J., Womble, A., Kennedy, A., Cai, S., C.S., Cleary, J., Dao, T., Leite, F., Liang, D., Peterman, K., Starek, M., Sun, C., Taflanidis, A., Wood, R., 2018. Hurricane Harvey (Texas) Supplement -- Collaborative Research: Geotechnical Extreme Events Reconnaissance (GEER) Association: Turning Disaster into Knowledge, DesignSafe-CI, Dataset, doi:10.17603/DS2Q38J

Ellenberg, A., Kontsos, A., Bartoli, I. and Pradhan A., 2014. Masonry crack detection application of an unmanned aerial vehicle. in Proceedings of International Conference of Computing in Civil and Building Engineering, Orlando, FL, pp. 1788-1795.

Federal Aviation Agency (FAA)., 2016. Fact Sheet – Small Unmanned Aircraft Regulations (Part 107), https://www.faa.gov/news/fact_sheets/news_story.cfm?news Id=20516

Fernandez G., J., Kerle, N., and Gerke M., 2014. UAV-based urban structural damage assessment using object-based image analysis and semantic reasoning. Natural Hazards and Earth System Sciences Discussions, 2: 5603-5645.

Ham, Y., Kevin K., Han, J., Lin, J. and Mani G., 2016. Visual monitoring of civil infrastructure systems via camera-equipped Unmanned Aerial Vehicles: a review of related works. Visualization in Engineering, 4, no. 1: 1.

Morgenthal, G. and Hallermann, N., 2014. Quality assessment of unmanned aerial vehicle (UAV) based visual inspection of structures. Advances in Structural Engineering, 17, no. 3: 289-302.

Na, S. and Jongdae B., 2016. Impedance-based non-destructive testing method combined with unmanned aerial vehicle for structural health monitoring of civil infrastructures. Applied Sciences, 7, no. 1: 15.

Van O., Geert J., Karin V., Antonia S., Roop S., Julie A., Friederike O., Karsten H., Sihan L., Gabriel V. and Heidi C., 2017. Attribution of extreme rainfall from Hurricane Harvey, August 2017. Environmental Research Letters, 12, no. 12 (2017): 124009.

Womble, J. A., Wood, R.L., Smith, D.A., Louden, E.I. and Mohammadi, M.E., 2017. Reality capture for tornado damage to structures. in Proceedings of Structural Congress 2017, Denver, CO. pp. 134-144.

Wood, R.L. and Mohammadi, M.E., 2015. Lidar scanning with supplementary UAV captured Images for structural inspections. in Proceedings of 2015 international lidar mapping forum, Denver, CO.