Preserving the Evidence: Multi-Platform 3D Reality Captures for Tornado Damage

Richard L. Wood, Ph.D.
Assistant Professor of Civil Engineering
University of Nebraska – Lincoln
rwood@unl.edu

J. Arn Womble, Ph.D., P.E.
Assistant Professor of Civil Engineering
West Texas A&M University
Canyon/Amarillo, TX
awomble@wtamu.edu

Presentation Outline
• Introduction (Learning from tornado damage)
• Equipment (Lidar and low-level aerial)
• Data processing
• Case Study (Pampa, TX Tornado - Nov. 2015) – NSF RAPID Response Grant

Objectives
1) Identify objective digital platforms for survey and assessment of structures
2) Prepare resultant data for quantitative analyses
3) Assess collected data for key features of interest

Digital Platforms
Motivation and Advantages
• Detailed and geometrically accurate
• Time efficient
• Cost effective
• Archived digital documentation
• Ease and safety of exposure:
  – Debris
  – Trip/Fall
  – Precarious structure

Objectives
Learning from Tornado Damage
• Need tornado wind speeds for engineering designs
• Few wind speed measurements (logistics and dangers)
• Damage to structures is a proxy for wind speed
  • Damage to engineered buildings is especially helpful
  • Revised/expanded DODs for EF Scale
• Need to validate (correct) wind speed estimates in EF Scale
• Preserving damage scenes is helpful for ongoing/future studies and validation of EF Scale

Ground Based Laser Scanner
Unmanned Aerial System
(above deployment)
Digital Platforms: LiDAR

**Equipment Overview**
- LiDAR Survey – “Light Detection and Ranging” or laser scanning
  - Determine surface geometries
  - Traditionally a pulse of light sent and “time of flight” calculated
  - Uses an exterior camera to capture RGB color indices
- Creates a point cloud
  - Vertices in 3D space
  - Measures distance, compute area, and volume
- Mesh or surface creation

**Digital Platforms: LiDAR**

**Equipment Constraints**
- Line of sight technology creates occlusions
  - Empty areas of the point cloud
- Various causes include:
  - Architectural features
  - Adjacent buildings
  - Tree branches and other landscaping features
  - Utility lines
  - Moving objects: people, vehicles, equipment, etc.

**Digital Platforms: LiDAR**

**Alleviating Constraints**
- Minimizing occlusions
- Use of multiple scans
  - Time consuming
  - Accessibility issues
- Typical solutions:
  - Mobile LiDAR via vehicle or robotic devices

**Digital Platforms: Low Level Aerial**

**Equipment Overview**
- Low level aerial imaging
  - Traditional fixed-wing aircraft
  - Unmanned Aerial Systems
- UAS Platforms can be flown:
  - Remote controlled
  - Semi-autonomous
  - Fully-autonomous
- Aerial onboard sensors include:
  - Cameras
  - LiDAR
  - Multi-spectral

**Digital Platforms: Low Level Aerial**

**Equipment Constraints**
- Line-of-sight technology in a moving reference frame
- Flight path determined by:
  - Environmental factors (e.g. wind, precipitation)
  - Regulations
  - Geometry of the target structure or system
  - On-board sensors
  - Situational obstacles

**Simulated Flight Path**
Digital Platforms: Low Level Aerial

Alleviating Constraints

- Flight plan optimization:
  - Desired resolution of onboard sensors
  - Duration (e.g. battery)
  - Altitude (e.g. detail level)
  - Obstacle avoidance
  - Direction (e.g. N-S, E-W)

Example Autonomous Path

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Resultant Data: LiDAR

Point Cloud Development

- Each scan position outputs point cloud in local coordinates
- Desired global coordinates for the entire system
- Point cloud registration done via targets
  - Retro-reflective spheres
  - Checkerboard patterns
  - Surveyed coordinates

Resultant Data: Aerial Imaging

Image Collection

Yes
Undistorted Images

No
Distorted Images

Point Cloud Formation

Yes
Scale SfM

No
Point Cloud Filtering

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Previosely Deployed Equipment

- DJI Phantom 2 with modified accessories
  - Range: 1000 m (3000 ft)
  - Duration: approx. 23 min.
  - Payload: 1300 g (2.8 lbs)
  - GPS auto-pilot system
  - First person camera view
- GoPro Hero 3+ Black Ed.
  - 12 MP photo capture
  - 1440 k video capture

Compact HD Camera

UAS before Takeoff in Bungamati, Nepal (abroad deployment)
Point Cloud Development

- Applied computer vision techniques to reconstruct 3D geometry
  - Structure-from-Motion
- General reconstruction process:
  - Identified image pairs via feature detection
  - Estimated image location and orientation
  - Reconstruct scene geometry

Example Ground Control Target

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Data Assessment: Geometry

- Convert (x, y, z) vertices to dimensioned drawings
- Computer Aided Drawings, Building Information Modeling
- Measure and geometric computations

Identify key dimensions

Data Assessment: Damage

- Assess surface geometry to identify features
- Global response
  - Displacement tracking
  - Structural drift
- Local response
  - Cracking
  - Spalling
  - Corrosion
- Basic steps
  - Data filtering and outlier removal
  - Point clustering and geometric computations
  - Statistical variation to detect changes
Data Assessment: Damage

• **Global Response:** Residual Drift

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**Note:** No data available in the Y direction for the 4th floors due to occlusion.

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**Data Assessment: Damage**

• **Local response**
  - Cracking, spalling, and corrosion is evident on surface due to local geometric variations
  - Investigate the local geometric variations over the neighborhood
    - Surface normal vectors
    - Curvature

• **Complications**
  - Ordered point cloud for computational efficiency
  - Computations for each point cloud vertex
    - Point cloud varies from 5k to 500M points
  - Requires high computational power

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**Data Assessment: Damage**

Example structure: El Centro, CA 2-story Masonry Infill RC Frame

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**Data Assessment: Damage**

Calculate Surface Normals

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Data Assessment: Validation

**Scalable Damage Detection and Validation**

- Qualitative assessment of detected damage
- Superimposing the detected damage to the point cloud

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**Case Study**

2015 Pampa Tornado

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**Tornado Outbreak**

Nov. 16-17, 2015 (TX – OK – KS)
**Helicopter and News Media (First Look)**

- Halliburton Oil Field Facility
- Low resolution, but helps to identify "pristine damage" areas

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**Why is this site so interesting?**

- Engineered buildings in close proximity - different resistances
- Damage levels serve as proxy for wind speed
- Revised/expanding DODs for EF Scale
- Metal buildings with overhead crane structure
- Facility was struck by a tornado in 1982 (under construction)
- No direct access (safety and security)
  - "What can we do to preserve these important data?"

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*Aerial Oklahoma Image (November 20, 2015)*

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*Aerial Oklahoma Image (November 20, 2015)*
Before (Google Earth)

After (Aerial Oklahoma)

Aerial Oklahoma (FoDAR 3D model)
(Aerial SfM)

Debris Field

LiDAR
(UNL and TTU)
Low-Level Aerial Images

A “puzzling” damage pattern (as viewed from ground)

The detailed video reveals why… (overhead crane)

Photogrammetry (PhotoModeler)

Current exploration for effectiveness (time and expense) compared to FoDAR and LiDAR

Preliminary results:
- Low cost
- Relatively rapid data collection
- Fine details possible
- Collection and processing area art forms

Center-Pivot Irrigation Systems

Potential new rural DI for EF Scale (ASCE Standard)
Conclusions

- First-available imagery is critical (any resolution) to distinguish pristine damage
- 2D data generally first available for initial analysis—3D can come later
- No single platform emerges as clearly the "best always overall"
- Choice of platform depends on situation (location, timing, personnel, budget)

High-Resolution Commercial Satellite
- Readily obtained
- Timing is tricky (revisit times and clouds)
- Expensive and relatively low resolution
- Near-IR imaging can be beneficial
- (Satellite is excellent for tornado paths over larger areas)

Aerial imaging tends to "win" over satellite for details of individual structures
- Possibility for 3D imaging based on overlapping images
- Especially good for following a tornado track
- Costs can vary with location
- Contract basis is excellent for urban areas; Custom/FoDAR system for other areas

Conclusions – cont.

- Low-Level Aerial
  - Highly useful
  - Government limitations and regulations
- Lidar
  - Excellent and straightforward results
  - Relatively slow – strategic choices only
- Digital photogrammetry
  - Data collection can be rapid
  - Relatively inexpensive rapid data acquisition, moderate acquisition speed
  - Data collection and post-processing are acquired

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Thank you!

J. Arn Womble
Assistant Professor of Civil Engineering
West Texas A&M University
awomble@wtamu.edu

Richard L. Wood
Assistant Professor
Department of Civil Engineering
University of Nebraska-Lincoln
rwood@unl.edu