The Use of Small Unmanned Aerial Vehicles for Post-Disaster Geotechnical Reconnaissance

Webinar Given April 20, 2016 by
Kevin Franke, Ph.D., P.E. Assistant Professor, CEE
Brigham Young University

Dimitrios Zekkos, Ph.D., P.E. Associate Professor, CEE
University of Michigan
Webinar Outline

- Welcome
- Types of UAV Platforms
- Types of UAV Sensors
- Current UAV Regulations
- Potential Uses for UAVs
- Case Histories
- Lessons Learned
- Questions/Answers
TYPES OF UAV PLATFORMS
Many, MANY different types of small UAVs commercially available today

These types can be generalized into three broad classifications:

1. Fixed Wing Platforms

- Trimble UX5
- Sensefly Ebee
- 3dr Aero Fixed
- Customized Ritewing
Types of UAV Platforms

- Many, MANY different types of small UAVs commercially available today
- These types can be generalized into three broad classifications:

2. Multi-Rotor Platforms

DJI Phantom  
DJI S1000  
Sensefly Exom
Many, MANY different types of small UAVs commercially available today

These types can be generalized into three broad classifications:

3. Single-Rotor Platforms

Customized Align T-Rex 800
Types of UAV Platforms

• **Fixed Wing Platforms**
  Pros: stable in wind, low vibrations, can carry large payload (...if large), typically longer flight endurance
  Cons: Harder for amateur to fly, some need landing space, difficulty imaging vertical objects, difficulty navigating in cluttered terrain, can have pixel blur due to higher velocities

• **Multi-Rotor Platforms**
  Pros: most stable flight (in no wind), can carry payloads up to about 7-10 lbs if large, easy to fly if includes stabilization/GPS technology, superior maneuverability, little space needed for takeoff/landing
  Cons: unstable in winds >20mph, short (~10-15 min) flight endurance per battery, sometimes susceptible to extreme temps

• **Single-Rotor Platforms**
  Pros: same as multi-rotor platform, but much more stable in windy and extreme temperature environments
  Cons: Generally same as multi-rotors, but more difficult to operate; high vibrations; can pose life-safety hazard
TYPES OF UAV SENSORS
UAV Sensors for Data Acquisition

- Number of sensors used for communication, flight control, and collision avoidance → not discussed today

- For field recon data acquisition, by far the most common are Vision-Based Sensors (e.g., cameras)

- Pictures (>12 MP) or Video (4k UHD video, i.e., higher resolution 3840 x 2160 pixels, better colors, higher video frame rate)

- Digital image processing can generate truly valuable data for geotechnical reconnaissance

- Key considerations for quality imagery data:
  - Weather (sunlight)
  - UAV viewpoint
  - Pixel Density for feature recognition (affected by camera characteristics and distance to target)
Mobility & Accessibility are key advantages of UAV-based imagery!

- **November 17th 2015** Mw 6.4 Lefkada earthquake (Greece)

  - November 19th 2015 (2 days later)

  **UAVs allow immediate access to field data that may be otherwise inaccessible by land or satellite**

  - April 12th 2016 (5 months later)
Also viewpoint is key advantage of UAV-based imagery!

- April 12th 2016 imagery

Dataset developed in collaboration with John Manousakis
UAV Sensors Beyond Visible Frequencies (RGB)

- LIDAR

- Near-Infrared $\rightarrow$ Esp. for vegetation

- Thermal

- Infrared

- Multi-Spectral $\rightarrow$ Combo of e.g., Visible, NIR, IR

- Hyper-Spectral

*Fig. By Victor Blacus - Wikimedia*
CURRENT UAV REGULATIONS
UAV Regulations

Current Regulations in the U.S.

- Messy! Can’t fly commercially w/out explicit authorization from the FAA (requires at least certificate of authorization, air worthiness certificate, registered UAV, and a fully-licensed pilot)
- FAA introduced the Section 333 Exemption in 2012 to expedite the certification process and allow commercial operation of small UAVs. To date, over 3,800 exemptions have been granted
- The Section 333 Exemption petition process has become log-jammed, and can require several months for an application to be processed
UAV Regulations

Pending Regulation Changes in the U.S.

- U.S. Congress has mandated that the FAA develop a set of practical rules that will allow the safe commercial operation of UAVs in the U.S.
- A draft set of regulations has been developed, and is awaiting approval and implementation (…possibly as early as summer 2016) (See the overview here: https://www.faa.gov/regulations_policies/rulemaking/media/021515_sUAS_Summary.pdf)

In general, UAVs will need:

- FAA registration (simple, online, $25-$50 fee)
- A licensed operator (...licensed by taking an online test)
- To stay below a max altitude of 500 ft above the ground
- Stay away from people not involved in the UAV operation, unless a special exemption (based on operator qualifications) is granted
- Operate only in the daytime and ONLY in Class G airspace
UAV Regulations

- **International Regulations**
  - Not standardized! Varies from country to country
  - Some countries (e.g., Australia, New Zealand) are quite open and favorable to commercial UAV operation. Others (e.g., India) are not
  - Must be considered on a case-by-case basis. It would be good for GEER to perform some preliminary “homework” regarding the current UAV regulations in various countries where reconnaissance work is frequently performed. If possible, obtain necessary authorizations now before potential extreme events occur
POTENTIAL USES FOR UAV-BASED DATA
Potential Uses for UAV-based Data

Aerial Imagery and Video

Port of Iquique, Chile – April 2014

From the Ground...

From the Air...

- See the “bigger picture” of the damage
- Avoid many occlusions
- Low altitude flight allows a unique combination of large field of view AND good image resolution
Potential Uses for UAV-based Data

Orthorectified Images and DEMs

What is an orthophoto?

Orthographic view

Perspective view

Datum plane

By SVG by User:Pieter Kuiper - Original
w:Image:OrthoPerspective.JPG by w:User:Kymstar, which probably was from "GIS fundamentals" by Paul Bolstad., Public Domain, https://commons.wikimedia.org/w/index.php?curid=5252153
Potential Uses for UAV-based Data

Orthorectified Images and DEMs

US Highway 89 Landslide, near Page, AZ – July 2014

• Use LiDAR or computer vision 3D point clouds to produce orthoprojections and/or DEMs

• DEM requires georeferencing of the point cloud

• Compatible with ArcGIS

Potential Uses for UAV-based Data

SfM 3D Point Clouds and Meshed Models

What is Structure from Motion Computer vision?

Images: CC - jdegenhardt, Bob Snyder, Jacques van Nierkerk, Kyle Wagaman, (Flickr)
Potential Uses for UAV-based Data

SfM 3D Point Clouds and Meshed Models

Molo Pier SfM 3D Model, Iquique, Chile – June 2014

- Developed from digital photographs
- Can require 48 hours+ to process a large model in-house

Tana Bridge, North of Iquique, Chile – June 2014

- Cloud computing requires 12-24 hours

*Franke, K.W. et al. (forthcoming) “Reconnaissance of Two Liquefaction Sites using Small Unmanned Aerial Vehicles and Structure from Motion Computer Vision Following the April 1, 2014 Chile Earthquake”, submitted to ASCE JGGE for review
Potential Uses for UAV-based Data

Change Detection Analysis for Measurement of Ground Movement – 2D or 3D

North Salt Lake Landslide – August 2014

Potential Uses for UAV-based Data

Manual Measurement of Ground Deformations or Other Objects of Interest

Molo Pier Liquefaction Site, Iquique, Chile – June 2014

*Franke, K.W. et al. (forthcoming) “Reconnaissance of Two Liquefaction Sites using Small Unmanned Aerial Vehicles and Structure from Motion Computer Vision Following the April 1, 2014 Chile Earthquake”, submitted to ASCE JGGE for review
• Many applications of UAVs in geophysics being considered, e.g., EM, hyperspectral, Magnetics, Seismic

• UAVs have the potential to revolutionize non-contact sensing technologies not only as data acquisition, but also as computational platforms

UAVs as Computational Platforms

- UAVs have already powerful on-board processors
- UAV processing capabilities currently used mainly as data acquisition platforms
- In the near future, we can expect drones to collect data, process it on-board, use it to make decisions, and collect additional, optimized, higher quality (e.g. definition) data

Nepal 2015 Earthquake co-seismic Landslides
UAVs for Data Dissemination and Decision Making

- Drones can now be used as standard data acquisition and dissemination platforms
- Dissemination can promote feedback by remotely connected professionals and experts

e.g., Lefkada 2015 Mw 6.4 Earthquake drone data collection
- Acquisition: 2 days after the EQ
- Dissemination: 4 days after EQ via Youtube
- 6,000 views within a week
CASE HISTORIES
Bridge Scour Failure in Kalampaka, Greece

- Failure location was physically inaccessible due to river
- 3-hr survey 2 days after the failure
- Failure was mapped using SfM
3D point cloud of the model

Mapped using 649 photos from a UAV at different points of view.

Point Cloud Density: 0.5 cm/pixel
Model error <1 cm

Dataset developed in collaboration with John Manousakis
The bridge pier *displaced*: 
1.38 m along bridge axis
0.91 m perpend. to axis
1.77 m vertically

The bridge pier *rotated*: 
5.7 degrees horizontally
Vertical inclination 29.1 degrees
UAV Case History #2
Sparmos Dam Failure & Flood Mapping

- 15 m high earth dam for irrigation
- Failure due to under-seepage
- Subsequent failure upon emptying due to rapid drawdown
- Survey conducted 2 days after failure in 4 hrs

Dataset developed in collaboration with John Manousakis
Mapping of rapid drawdown failure

Original Geometry

Failure Surface
UAV Case History #2

Dam Failure & Flood Mapping

Volume of Water Release: 85,000 m³

Structural Damage Assessment

- Model scaled using RTK GPS
- 12 GPS points used for model scaling
- 6 GPS points for model error assessment
- Total Mean Error ±2.5 cm

Water flooded area: ~100,000 m²

Zekkos et al. (2016). “UAV-based Reconnaissance following Recent Natural Disasters in Greece.” International Conference on Natural Hazards and Infrastructure, 28-30 June 2016, Chania, Crete Island, Greece (submitted). Dataset developed in collaboration with John Manousakis
Characterization of Monsoon-induced Debris Flow

- DTM generation (Ground Sampling Distance – GSD = 5.0 cm/pixel)
- ~ 3 cm total mean error between GPS measured coord. and 3D model generated coord.
- Imagery can be used for grain size analysis to gain insights on dynamics of debris flow

UAV Case History #3

50 m

Finer Grains (sand)

Coarser Grains (boulders)

Dataset collected in collaboration with Prof. Marin Clark, University of Michigan, and Prof. Joshua West, USC
Vasiliki Port Pier Damage during 2015 Mw 6.4 Lefkada earthquake, Greece

- 12 m wide, 73 m long port pier
- 7 min flight length
- 5 m flight height
- Ground Sampling Distance 0.5 cm/pixel

Automatic identification of cracks per Jahanshahi et al. 2011

LIDAR vs. SfM 3D point Clouds

- Complex set of co-seismic landslides in Nepal
- Landslides ~200 m in height
- 10 cm/pixel with drone flying ~120 m away
- 3D point clouds practically identical

Oblique View of drone-based SfM 3D point cloud

Lidar dataset courtesy of Dr. Kristen Cook, Potsdam University
Image Analysis can be used to characterize the mechanical characteristics of rock (e.g. GSI for Hoek and Brown materials) or attitude of discontinuities for structurally controlled failures.
UAV Case History #7

Landslide Modeling and Deformation Measurement

- Landslide in North Salt Lake, Utah – August 2014
- Slide started moving again this week! ...Over 5 inches!

https://www.youtube.com/watch?v=IP4bSv7apcA
Landslide Modeling and Deformation Measurement

- Landslide has now been stabilized, highway repaired

https://www.youtube.com/watch?v=IGE4ySPd5RU
Rock Outcrop Modeling and Critical Layer Detection

- Book Cliffs, Son of Blaze Canyon, Central Utah – June 2014
- Interest in manually identifying rock layers of interest, including sandstone and/or coal seams

https://www.youtube.com/watch?v=gLzKkhhR7Q4
LESSONS LEARNED FROM THE FIELD
UAV Field Lessons Learned

Major Considerations

- UAVs control and sensing capabilities evolving greatly
- Regulations are also evolving
- Safety → UAVs can cause injuries or even death. Safety Protocols need to be followed
- Flying a UAV well does require practice
- Acquiring good quality technical field data requires even more practice, experience and appropriate equipment: Type of drone, flight parameters (elevation, distance from target, point of view), sensor (e.g., camera characteristics), type of data and acquisition parameters (e.g. frequency), will impact quality of data (resolution, density of cloud, ability to identify feature).
- Each flight should have a specific objective of collected data
- For quantitative measurements of UAV data, land-based GPS or other similar
Environmental/Weather Considerations

- It is crucial to match the UAV and pilot to the environment/weather considerations
- Many UAVs are sensitive to wind (>15-20mph) and moisture
- Some UAVs (particularly multi-rotors) can be sensitive to temperature
- Single-rotors are usually more robust to the environment than multi-rotors

Example: An attempt to fly a small quadrotor to image a large rockfall failed when a sudden wind gust made the UAV lose radio connection with the operator. The UAV initiated auto-landing, but the wind blew the descending UAV into the mountain. It was buried under 6 feet of snow, and retrieved nearly 5 months later.
UAV Field Lessons Learned

Necessary Hardware/Software

• Good UAVs do not need to be expensive, particularly if you manually upgrade a hobbyist aircraft
• Commercial ready-to-fly UAVs can be $$$ (>40k in cost), particularly if they have lots of specialized features (e.g., automation)
• Larger UAVs require lots of maintenance. Helps to have an experienced technician oversee them. Small hobbyist UAVs usually require minimal maintenance unless you crash them
• Plan on having multiple sets of batteries and means to charge them in the field. Batteries must be replaced annually if you fly a lot
• Reliable sensor gimbals are a challenge, particularly with larger sensors
• There are lots of SfM software options. To operate SfM in-house, best to have a workstation computer (cost ranging from $5k to $20k+ depending on configuration. Needs lots of graphics memory)
• SfM cloud computing becoming quite popular, but limits the ability to control the 3D reconstruction
The Realities of UAV Automation

The Internet sometimes leads us to believe that UAVs are much more intelligent than they really are. We hear stories about UAVs delivering packages, repairing infrastructure, stopping crimes, etc.,
The Realities of UAV Automation

- Internet UAV videos usually show one unique skill that the UAV has been trained to do in a known environment
- The reality is that UAV/robotics experts are still struggling to solve basic automation problems such as “perch and stare” and “vision-based navigation”
- Almost all useful UAV automation that is available on commercial hobby aircraft today is dependent upon GPS. Without GPS, most UAV automation does not function well or at all
- Most current automated algorithms allow flight plans to be programmed pre-flight or mid-flight, but these will lock the UAV altitude (i.e., the UAV can only maneuver horizontally, not up or down)
- Automatic take-off/landing functions generally work well when GPS signal is present and good weather conditions exist
- Windy weather + automated flight = significant increase in battery drain!
The Use of Small Unmanned Aerial Vehicles for Post-Disaster Geotechnical Reconnaissance

Webinar Given April 20, 2016
by
Kevin Franke, Ph.D., P.E.
Assistant Professor, CEE
Brigham Young University
and
Dimitrios Zekkos, Ph.D., P.E.
Associate Professor, CEE
University of Michigan