RAPID NHERI
Natural Hazards Reconnaissance

# Hardware, Software, and Instrumentation

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NSF Award Number: CMMI 1611820

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# MULTI-HAZARD INTERDISCIPLINARY INSTRUMENTATION

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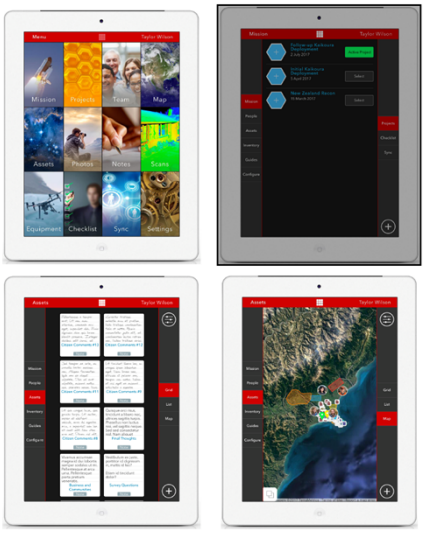
# RAPID App or "RApp"

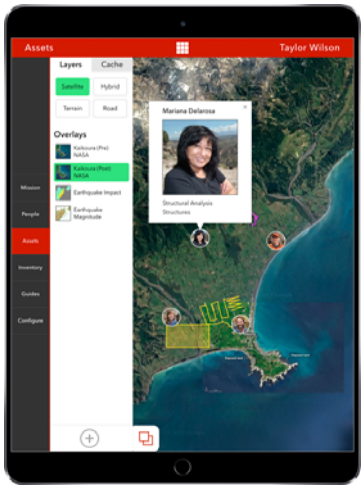
RApp integrates mission planning and coordination, data collection, and data management into a single, unified package

*RAPID App graphical user interface prototype.*



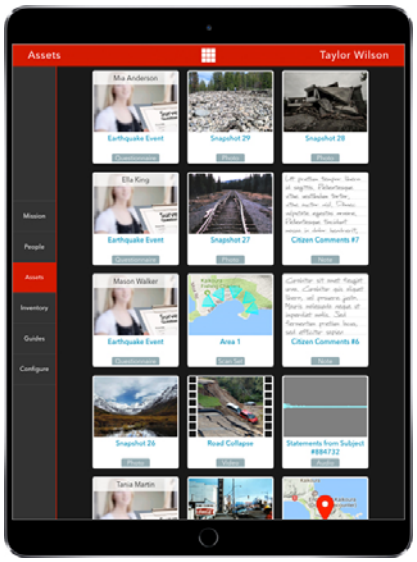
- Afford users the ability to identify, capture, aggregate, organize, store, and manage social science, engineering, and natural science reconnaissance data
- Disseminate, analyze, and visualize those data
- Facilitates communication, coordination, and collaboration among researchers across disciplines
- Designed with a human-centered approach that includes user research, ideation, prototyping, and iteration.

# RApp: Mission Planning




- Mission Coordination
- Cacheable Maps
- Route, Area, and Location Planning
- Location Tracking
- Inventory
- Checklist
- Data Synchronizing

## RApp: Data Collection




- Photos, Videos, Audio, Notes, Scans, Surveys, Questionnaires, and More
- Data Tagging
- Data Linking
- Guides for Multi-Disciplinary Data Collection
- Data Upload to DesignSafe

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## Mobile Software Suite

Companion apps will be included alongside the RAPID App to provide additional capabilities.

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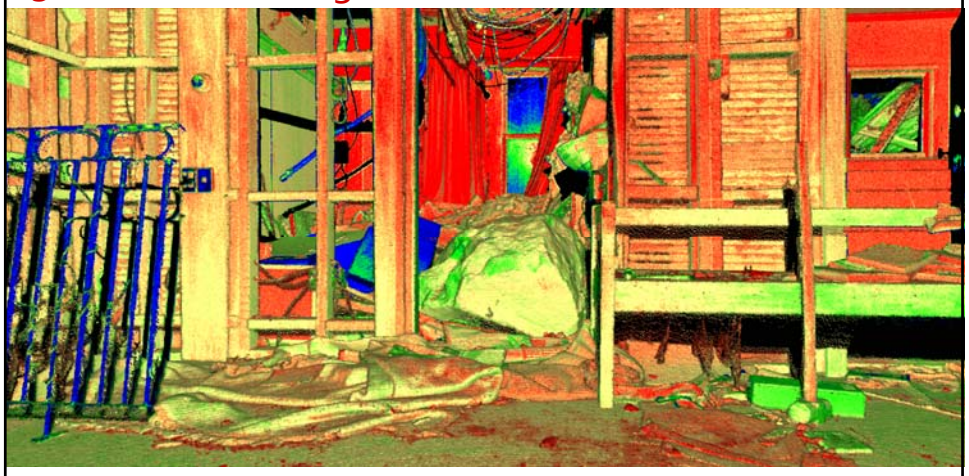
## 3D Laser Scanning



- Highly versatile – Collect once, use many
- Digitally preserve scene at high detail, accuracy
- Applicable across spatial scales

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## 3D Laser Scanning: Equipment

Leica BLK360 (x3)

Maptek XR3

Maptek LR3

- Short and long range systems
- Simple, easy to use interfaces
- Portable and durable
- Streamlined workflows

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## Leica BLK 360 – 3 units

- 3 min scan + 150 MP pano photograph + thermal image (depends on resolution)
- FOV: 360° Horizontal, 300° Vertical
- 360,000 points per second
- HDR imaging capabilities
- Small & Lightweight (2.2 lbs, 6.5" tall) -> carry on
- Indoor/outdoor
- Range (Short) 60 m
- Accuracy good (~6mm 3D RMS @ 10 m)
- Auto registration capabilities

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## Leica BLK360 applications

- Structures: inside and outside
- Small sites, localized features of interest
- Capturing topography at sites difficult to get to (hike in, hike out) or with difficult terrain.
- Can be used to capture additional dimensions and imagery at a site while the reconnaissance team records notes of observations or obtains other measurements.

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## Maptek LR3 (Long Range) Specifications

Maptek LR3

- Max Range 1200 m
- 147 MP HDR panoramic Image
- Field of view: 360 H, 100 V
- Dual axis level compensator
- Max resolution (0.0125 deg)
- Range accuracy (4mm @65 m)
- Digital Compass (+/-1 deg)
- Internal L1 GPS – can mount external Survey Grade GNSS on top
- Acquisition Rate (ranges based on 80% reflectivity)
  - 200kHz (up to 300 m)
  - 100kHz (up to 600 m)
  - 50kHz (up to 1000 m)

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## Maptek XR3 (Extra Long Range) Specifications

Maptek XR3

- Max Range 2400 m
- 147 MP HDR panoramic Image
- Field of view: 360 H, 100 V
- Dual axis level compensator
- Max resolution (0.0125)
- Range accuracy (5mm @65 m)
- Digital Compass (+/-1 deg)
- Internal L1 GPS – can mount external Survey Grade GNSS on top
- Acquisition Rate (ranges based on 80% reflectivity)
  - 200kHz (up to 500 m)
  - 100kHz (up to 1100 m)
  - 50kHz (up to 2200 m)

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## Maptek LR3 Applications

- Topographic mapping and digital elevation models (DEM)
  - Landslides, rockfalls, lateral spreading and other liquefaction features
  - Coastal features
  - Dam monitoring
- Infrastructure including: building exteriors (particularly tall or distant buildings), bridges, etc.
- Long sections of highway (infrastructure) – in the future RAPID will have a mount to support stop and go mobile platform for this scanner.
- XR3 is the similar to the LR3 but enables capture of data from landslides, rockslopes, slopes, and other features of interest at much longer long ranges.

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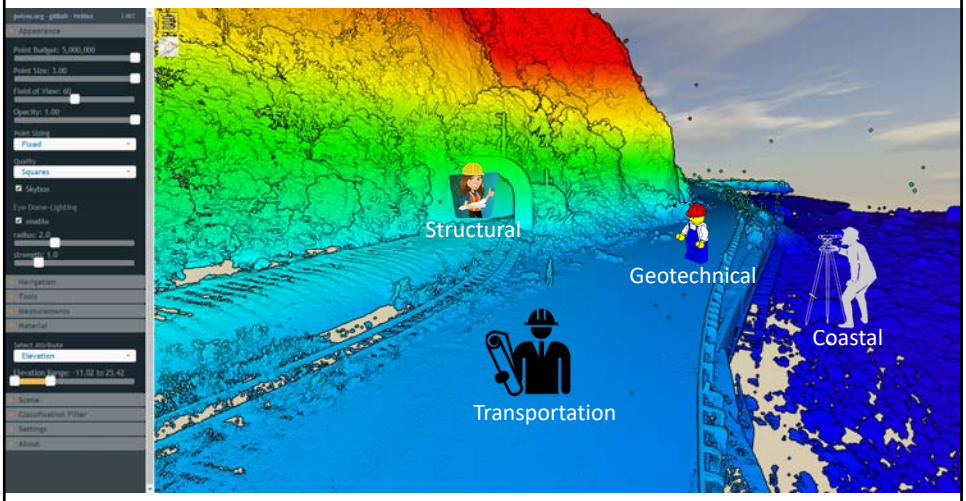
## 3D Laser Scanning
### 2016 Kaikoura Earthquake

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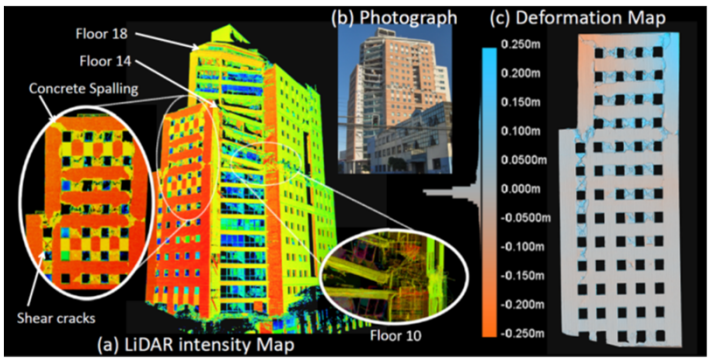
# 3D Laser Scanning
## 2010 Maule Chile Earthquake and Tsunami




Data from the 2010 Maule earthquake collected using Riegl VZ-400 scanner (Olsen et al., 2012). Image (c) shows out of plane displacement due to rotation at 10th story computed using lidar data.

Point Clouds:

- Offers potential for rapid data collection
- Digital site preservation.
- Lidar data can be used to *manually* identify and quantify damage.
- Current research addresses automated damage detection and quantification.

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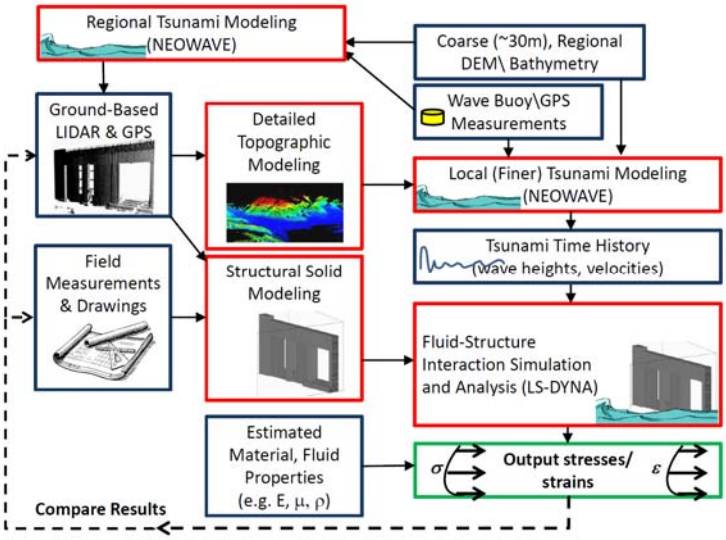
# 3D Laser Scanning
## 2011 Tohoku Japan Tsunami




Yim et al. 2014

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# 3D Laser Scanning

## 2013 Moore, OK Tornado

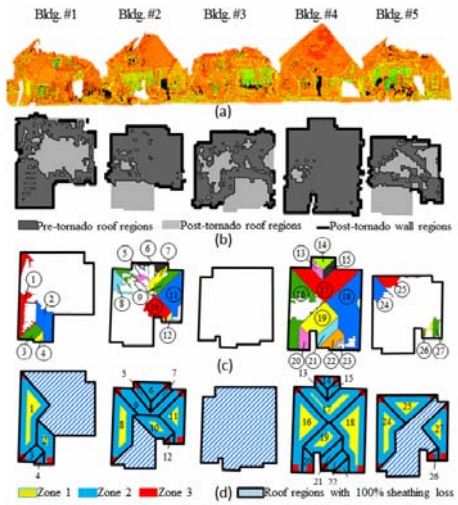


**Fig 4.4.** The Moore, OK, Case study; (a) LiDAR data collected after the 2013 tornado, (b) detected building roof and wall regions, (c) detected post-tornado roof polygons, (d) reconstructed pre-tornado roof polygons and pressure zones

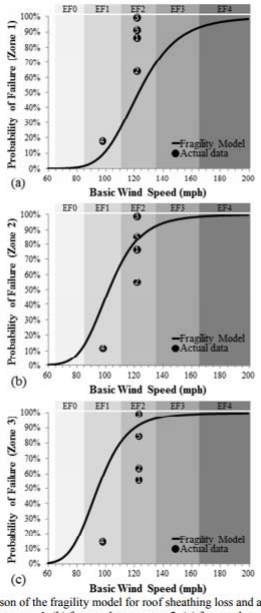


**Fig 4.5.** Comparison of the fragility model for roof sheathing loss and actual data; (a) for panels over zone 1, (b) for panels over zone 2, (c) for panels over zone 3

Kashani (2014). Automated assessment of tornado-induced building damage based on terrestrial laser scanning. PhD Dissertation, Advisor: A. Graettinger, University of Alabama

# Surveying Technologies

- Standalone surveys or integrated with other devices
- Ensures high quality geo-referencing capabilities

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## Surveying Technologies: Equipment

Leica Nova TS60I Total Station

Leica GS18T GNSS (x4)

Leica LS15 Digital Level

- Total station with reflectorless, robotics, and imaging capabilities
- GNSS receiver with improved positioning with obstructions
- High precision digital level

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## Leica TS16I - Total station

Leica Nova TS60I Total Station

- Robotic
- Imaging
- GNSS mounted on top
- Local site survey
- Capture control points for lidar or sfm surveys
  - Improved relative accuracy over GNSS for local sites
  - Faster acquisition due to robotics
- Tag features of interest with attributes upon acquisition
- Accuracy typically a few mm

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## Leica GNSS 18

Leica GS18 GNSS (x4)

- Not just GPS- GNSS
- Base\rover setups
- Tilt compensation– compensates for out of plumb observations and can capture the corner of a building (Still should follow best practices!)
- Integrated IMU also enables precise positioning underneath obstructions such as a bridge
- Obtain coordinates for ground control points for UAS SfM
- Place atop scanners for accurate positioning
- Utilize with Z-Boats

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## Leica LS15 digital level

- Tilts
- Flatness of slabs
- Profiles of a coastline
- Capable of sub mm elevation differences
- Improved elevation for control points over GNSS/total station
- Many models focus on distinguishing moderate to large damages but have a very hard time distinguishing minor damages from none or moderate damage.

Leica LS15 Digital Level

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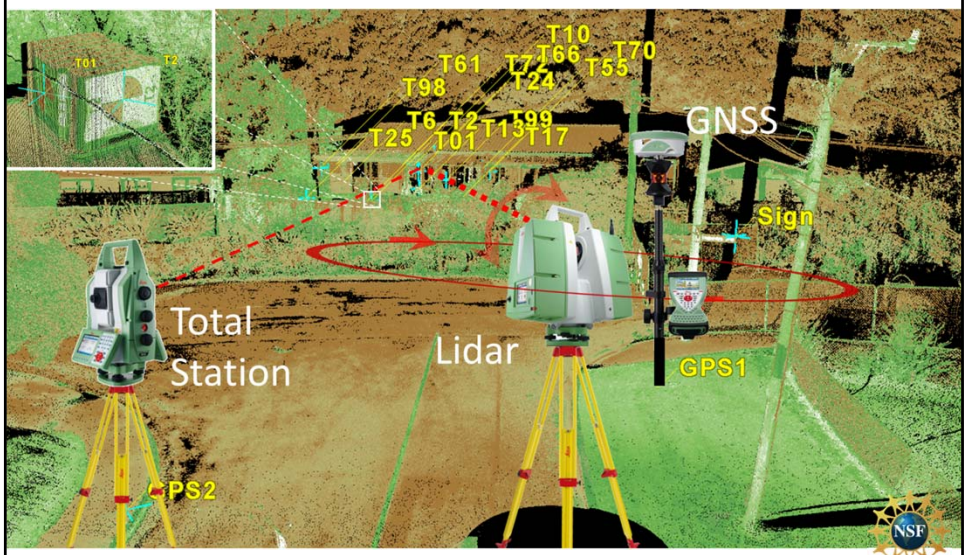
## Surveying Technologies: Example Applications




Seismic Rockfalls, Christchurch, New Zealand (Olsen & Gillins, 2015)

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## Unmanned Aircraft Systems (UAS), or *Drones*

- Provide a range of perspectives and scales
- Cost effective, safe, and relatively easy to use compared to manned aircraft
- Access areas otherwise inaccessible
- Versatile; can be outfitted with multiple data acquisition tools and sensors

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## UAS: Equipment

- Hobbyist drones: lower resolution data for damage assessment
- Consumer-grade: aerial photography for SfM
- Industrial: weatherproof, high-resolution data for SfM
- MiniRanger: lidar system, survey grade, can also be mounted to vehicle

Mavic Pro/Air

Parrot Disco Adventurer

Phantom 4 Pro+

Inspire 2

Matrice 200 Series

MiniRanger



## Mavic Pro/Air and Fixed Wing Platform

- Parrot Disco
  - HD camera
  - Flight time: 45 mins, Max speed: 50 mph
  - Range: 1.2 miles

- Mavic Pro/Air
  - 12 MP, 4K/30fps, 3-axis gimbal camera (Air panaramas to 32MP)
  - Flight time: 27 mins, Max speed: 40 mph
  - Range: 4.3 miles (Pro), 2.5 miles (Air)
  - Flight Autonomy / Obstacle Avoidance
  - Quick deployments, and Scouting

## Phantom 4 Pro+

- 1 in 20 MP, 4K/60fps, 3-axis gimbal camera, mechanical shutter
- Flight time: 30 mins, Max speed: 45 mph
- Range: 4.3 miles
- Flight Autonomy / Obstacle Avoidance
- Narrow Sensing Mode (navigate without GPS)
- Built-in 5.5-inch 1080p screen with 1000 cd/m2 brightness, 5 hour battery and 16GB storage
- Small, light, general purpose drone

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## Inspire 2

- 1 in 20 MP, 4K/60fps or 5.2K/30fps, 3-axis gimbal X4S camera (interchangeable)
- Dual streaming from FPV and main (X4S) camera
- Flight time: 27 mins, Max speed: 58 mph
- Range: 4.3 miles
- Flight Autonomy / Obstacle Avoidance
- High resolution camera

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## Matrice 210

- 1 in 20 MP, 4K/60fps or 5.2K/30fps, 3-axis gimbal X4S camera (interchangeable)
- Dual streaming from FPV and main (X4S) camera
- Single downward, single upward, dual downward gimbal or third party sensors
- Flight time: 23 mins, Max speed: 52 mph
- Range: 4.3 miles
- Flight Autonomy / Obstacle Avoidance
- Can fly in high winds
- Weather Resistance

| | | |
|---|---|---|
| IP43 | Protected from tools and small wires greater than 1 millimeter. | Protected from water spray less than 60 degrees from vertical. |

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## Phoenix miniRanger "lidar drone"

- cm-level accuracy
- 9MP global shutter RGB camera
- RTK GNSS
- High quality IMU (upgrade)
- Abs Accuracy (25H/35Vmm RMSE @100 m range
- 100k shots per second, up to 5 returns per shot
- Real-time post processing (custom software)
- Flight time: ~24mins, Max speed: 40mph
- Fully autonomous, can be mounted on any drone, car, boat and/or even backpacks

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## UAS: Applications

- Phoenix miniRanger (lidar)
  - Surface and bare earth models
- Other UAS (SfM, imagery)
  - Topographic mapping (not as precise as lidar, but larger coverage) of coastlines, landslides, infrastructure
  - Up close (virtually) Structural assessments of exteriors of tall buildings, bridges – difficult to reach otherwise

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## UAS: Example Applications

2015 Bungmati, Nepal

Data Courtesy of Dan Gillins and Farid Javadnejad, OSU

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## Applied Streetview

Google Streetview deployment after Tohoku Earthquake

- Your own, personal Streetview
- 360-degree, car-mounted camera
- GNSS georeferencing
- Scrub sensitive info (faces, license plates)
- Easy mount to vehicle
- Visualization Software for organizing and querying projects

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## DJI Osmo and Insta360

DJI Osmos & 4K Camera

Insta360 ONE

NYTimes Daily 360

- Stabilized, walkthrough imagery
- 4k resolution
- 12MP (Osmo), 24MP (Insta360)
- Ability to capture high resolution data quickly
- Ideal for "tight" spaces

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## Digital SLR cameras

Canon 7D Mark II (x3)

- Capture high quality overview/general images
- Significant improvements in terms of SNR, lighting control, white balance, etc.
- Smartphones/Ipads take good images, but have many limitations in terms of distortion, quality, etc. for processing
- Use this for detailed images of damaged components in structure or images collected for quantitative computational analysis
- Build SfM models with high quality images!

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## GigaPan Epir Pro V

Gigapan Epic Pro V

- Works with the digital SLR cameras (and others)
- Seamless integration of multiple images to create high resolution (gigapixel) images –enabling analysis across spatial scales
- Rock slope or panoramic view of terrain
- High quality imagery of the façade of a structure
- Overview oblique imagery of a town from a hillslope viewpoint to put observations/measurements in context, etc.

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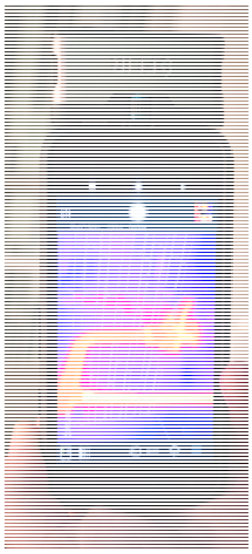
## Thermal Imaging



FLIR One Pro

- MSX-enhanced thermal images
- Plugs directly into mobile device
- Measures temperatures < 400° C
- Damage assessment, electrical signatures, water damage

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# MISCELLANEOUS

NSF Award Number: CMMI 1611820

## Rap Pack

- Ready to go backpacks with smaller tools important to recon
- Inexpensive items potentially challenging to round up on short notice:
  - Smart device with camera, GPS, etc.
  - Measuring tapes (soft and hard)
  - Digital Calipers
  - Leica Disto D2 Range Finder
  - First Aid Kit, Safety Glasses
  - Hand level
  - Pocket Rod
  - Plumb Bob
  - Weld Gauge
  - Crack Gauge
  - Etc.

Smart Devices (Chen et al. 2013 & Intergraph Corp. 2013)

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## Miscellaneous Items

- Some items could be added to the RapPacks or will be used with other RAPID equipment
  - Goal Zero Yeti 150 and 400 batteries
  - NHERI Rapid safety vests with iPad pocket
  - Pelican Cases
  - Power Inverters
  - Walkie Talkies
  - Etc.

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# COASTAL HAZARDS EQUIPMENT

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## Coastal Monitoring and Investigation

- Characterize transient and variable nature of the loading actions from coastal hazards
- Enable robust simulation of loading from coastal hazards
- Characterize post-event recovery processes
- Characterize effectiveness of mitigation actions (gray, green, hybrid, nonstructural)
- Capture bathymetry, topography, inundation

Bullets modified from NHERI Science Plan (2017)

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## Coastal: Equipment & Applications

- GPS/GNSS
- High consumer grade cameras
- Total stations
- Digital levels
- Laser scanners (lidar)
- UAS
- Lidar UAS
- Z-Boat single beam sonar & underwater camera
- Pressure sensors

- Inundation/flow depth
- Wave characteristics
- Damage zones
- Topography
- Bathymetry
- Erosion/deposition

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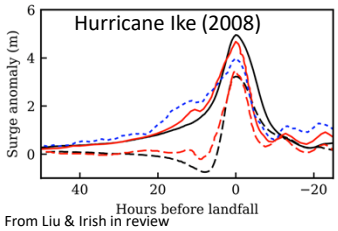
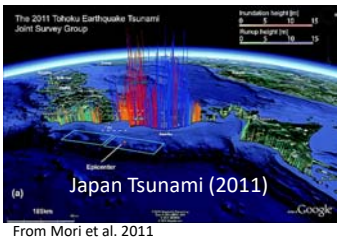
## Coastal: Example Applications



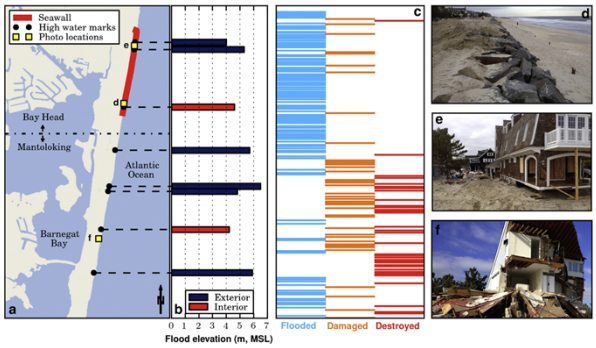

From Liu & Irish in review
(some data from Kennedy et al. 2011)




From Mori et al. 2011

Hurricane Sandy (2012)

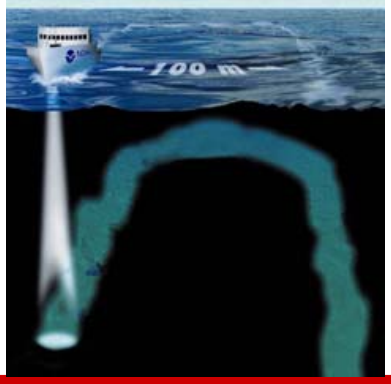
From Irish et al. 2013






## Coastal: Equipment

- **Surface UAV with singlebeam sonar**
- Accurate bathymetric transects
- Teledyne Z-Boat with Odom CV100 Echo Sounder
  - Bottom type/features
  - Erosion/deposition
  - Infrastructure damage
- Researcher-supplied equipment



## Coastal: Equipment

- **Pressure sensors (20)**
- Time series of:
  - Flow depths
  - Surge heights
  - Runup heights
  - Storm waves
- TruBlue 255 x 20
- Water level and wave measurement. Onshore and nearshore/offshore (using beacons) for storm surge etc.

USGS 2017

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# SOCIAL SCIENCE

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## Social & Citizen Science

- Mixed method data collection for social impacts, response, and recovery
- Integration of data collection tools
- Incorporation of workflow management

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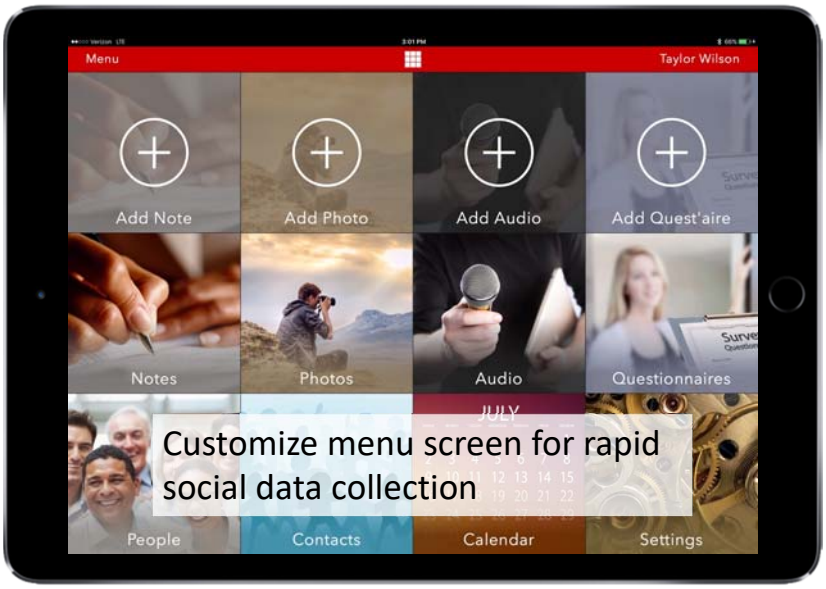
## Social & Citizen Science: RApp for Social Data




Customize menu screen for rapid social data collection

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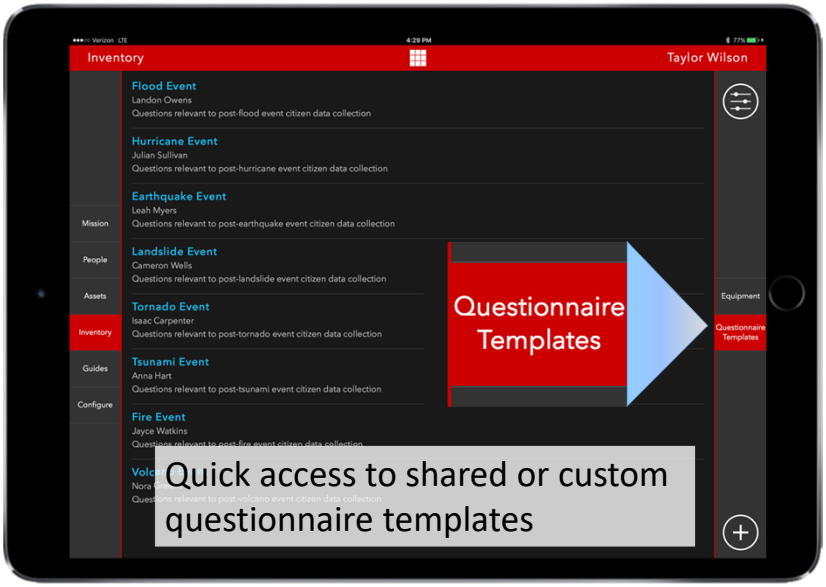
## Social & Citizen Science: RApp for Social Data

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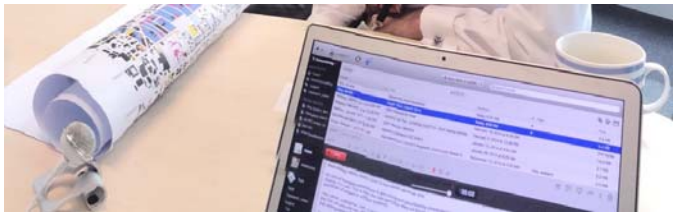
## Social & Citizen Science: Use Cases

Typed, hand-written, and audio notes

Future integration with other notetaking apps



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## Social & Citizen Science: Citizen RApp

Version of RApp designed to support researchers to conduct citizen science research & data collection

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## Social & Citizen Science: Citizen RApp

Simplified interface, reduced & custom functionality with same workflow and data integration (e.g., DesignSafe-CI)

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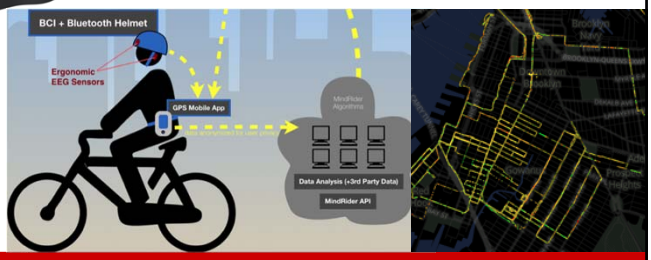
## Social & Citizen Science: Equipment

- EMOTIV EPOC+ 14 channel wireless EEG (electroencephalography)
  - Mobile Wireless Brain-Computer Interface
  - Track conscious thought, emotions, facial expressions, head rotation, and location (w/ smart phone or tablet)

For example….

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# SITE CHARACTERIZATION AND GROUND INVESTIGATION APPLICATIONS

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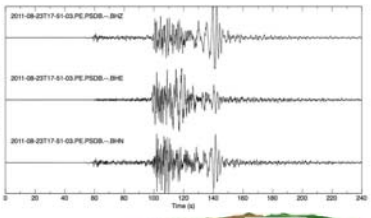
# Site Characterization

Table: NEHRP seismic site classification based on shear-wave velocity (Vs) ranges.

| Site Class | S-Velocity (Vs) (ft/sec) | S-Velocity (Vs) (m/sec) |
|---|---|---|
| A (Hard Rock) | > 5,000 | > 1500 |
| B (Rock) | 2,500 – 5000 | 760 – 1500 |
| C (Very Dense Soil and Soft Rock) | 1,200 – 2,500 | 360 – 760 |
| D (Stiff Soil) | 600 – 1,200 | 180 – 360 |
| E (Soft Clay Soil) | < 600 | < 180 |
| F (Soils requiring additional response) | < 600, and meeting some additional conditions. | < 180, and meeting some additional conditions. |



- Measurement of the dynamic properties (i.e., Vs, $F_n$) of the geologic media that underlies a site
- Dynamic properties govern a site's response to strong ground motion and are critical for understanding the ground motion characteristics at a site

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# Trillium Compact Seismometers

Trillium Compact Seismometer (x6)

Centaur Digital Recorder

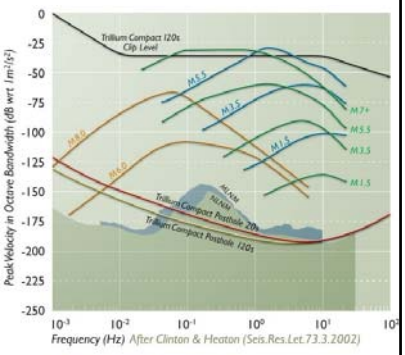
Seismometer

- Flat velocity from 20 sec (0.05Hz) to 100Hz
- Tilt tolerance of 10°
- 90mm diameter, 100mm height
- 2.6 pounds
- IP67 rating
- 750 V-s/m sensitivity
- 26 mm/s clip level from 0.1-10Hz
- No parasitic resonances below 200Hz

Recorder

- 3 channel, 24 bits per channel
- 8GB Storage
- GPS Receiver
- Can apply bandpass filters and calculated PGA, PGV, PGD in field
- Transfer data with Ethernet, WiFi, SD-card swap

| | | |
|---|---|---|
| IP67 | Protected from total dust ingress. | Protected from immersion between 15 centimeters and 1 meter in depth. |

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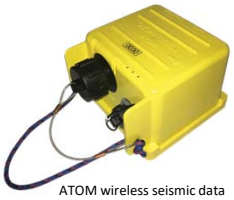
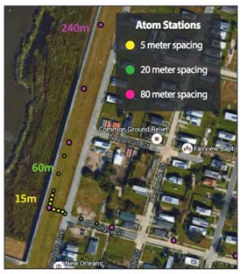
# ATOM Wireless Seismic Data Acquisition

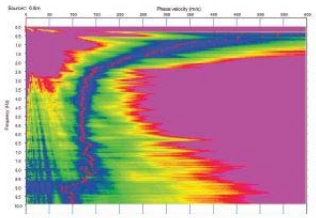


ATOM wireless seismic data acquisition system (x24)

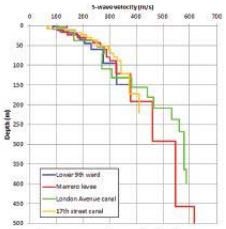



- Passive system, 24 units, 24-bit
- 0.2 to 1,650 Hz bandwidth
- 142 x 140 x 120 mm
- 3.5 pounds (per unit)
- IP68 rating
- Internal power, Shake to turn on
- GPS controlled timing
- Retrieve data with WiFi
- 4GB storage (70, 8-hr days at 4ms sample rate)
- Shear wave data up to 1km deep
- Seisimager software for processing data

| | | |
|---|---|---|
| IP68 | Protected from total dust ingress. | Protected from long term immersion up to a specified pressure. |



Surface wave dispersion curve



Shear wave velocity-depth plots

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# Site Characterization: Example Applications

- Seismometers
  - Measure aftershock motions
  - H/V measurements to estimate site fundamental frequency
  - Site and topographic effects
- ATOM seismic acquisition units
  - H/V measurements to estimate site fundamental frequency
  - Shear wave velocities using Multichannel Analysis of Surface Waves (MASW)

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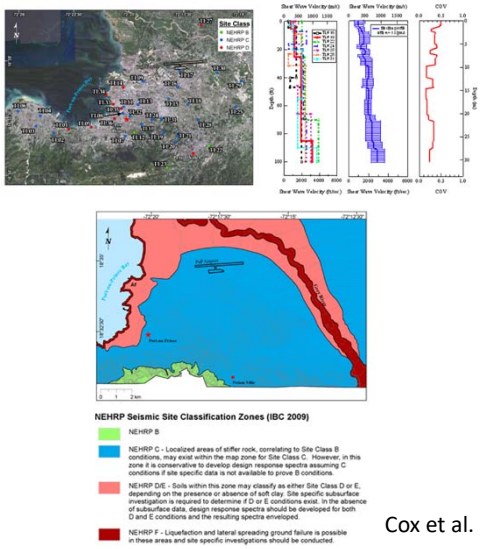
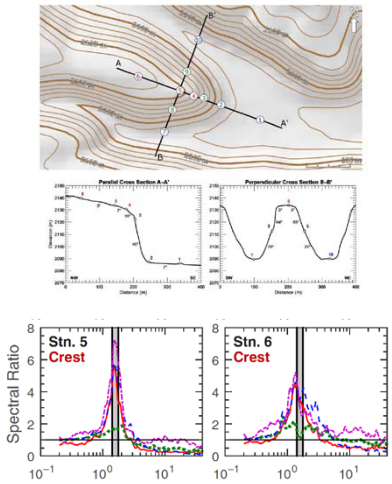
## Site Characterization: Example Applications



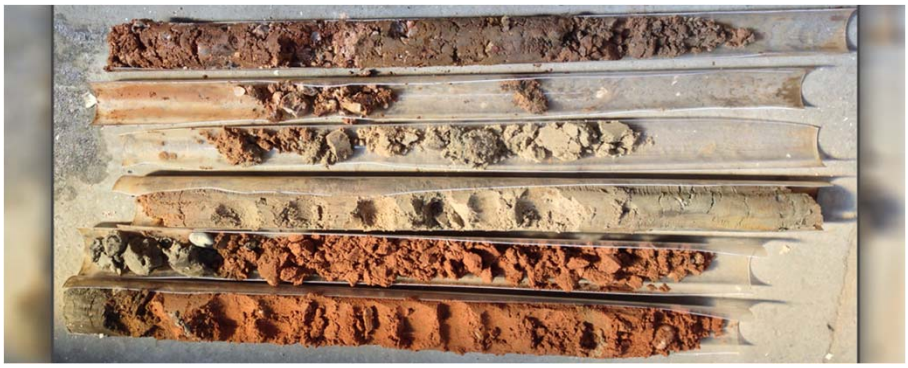

Cox et al. (2011)




Stolte et al. (2017)



## Ground Investigation



- Subsurface characteristics strongly influence the response of geotechnical systems (including foundations, levees, slopes, etc.) to extreme events such as earthquakes, tsunamis, and hurricane storm surges.

## Ground Investigation: Equipment

Hand-held Smart Dynamic Cone Penetrometer

Basic Soil Sampling Kit

SilverSchmidt and RockSchmidt Hammer

Pocket Penetrometer

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## Ground Investigation: Applications

- Hand-held digital cone penetrometer (SmartDCP):
  - In situ shallow ground characterization (up to 6 feet), blow counts, in situ density, stiffness, strength
  - Records blow counts, penetration depth per blow, total depth, and calculates and plots CBR in real time; data collected on smart device
- Pocket Penetrometer:
  - In situ soil strength characterization, small sample
- SilverSchmidt and RockSchmidt Hammers:
  - In situ compressive strength of rock or concrete
  - Digital display, pre-programmed methods for calculating strength
- Soil Sampling Kit:
  - Hand auger (up to 12 feet), retrieve samples for lab studies
  - Regular, sand, and mud augers and slide hammer
  - Plastic lined sampler with plastic end caps

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Natural Hazards Reconnaissance

# COMPUTING

NSF Award Number: CMMI 1611820

## RAPID staff can perform or assist you with

- Field data collection using RAPID instrumentation at your field or lab location
- Processing lidar and imaging data using structure from motion (SfM) techniques
- Data visualization using our computer automated virtual environment (CAVE)
- Processing and interpreting specialized data (i.e., site characterization/ coastal)
- Archiving data using DesignSafe, which integrates with the RAPID App

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## RAPID Computing

- Processing workstations (x2)
  - Intel Core i9-7900X 10 Core 3.3 GHz Processor
  - 64 GB DDR4 SDRAM Memory
  - Dual NVIDIA GeForce GTX 1080 Ti Graphics Cards
    - 11GB Video RAM each
  - PCI Express and SATA III Solid State Drives
  - 32" 4k UHD monitor or 2 x 24"

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## RAPID Computing

- Field Laptops (x2)
  - Intel Core i7-7700 HQ, 2.8GHz Processer
  - 16 GB DDR4 2400 RAM Memory
  - NVIDIA GeForce GTX 1070 GDD R5 8GB Graphics Card
  - SSD
  - 15.6" UHD, anti-glare screen

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## RAPID Computing

10.5-inch iPad Pro

Tripod

HD Microphone

Tripod Adapter

256GB Wireless Stick

External Battery

DJI Fly 2TB Drive

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## Processing software @ RAPID

- Leica Infinity – GNSS and total station processing
- Leica Cyclone – Laser scanning software
- Autodesk Recap – Laser scanning software
- Maptek I-Site Studio – Laser scanning software
- Terrasolid – Processing UAS lidar data
- Pix4D – Structure from Motion & UAS flight planning
- Agisoft Photoscan – Structure from Motion & UAS flight planning
- Custom processing programs to make data processing\analysis efficient and simpler – "the secret sauce"
- Software available @ RAPID and on field laptops

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## Virtual Reconnaissance – Mini-CAVE

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## Virtual Reconnaissance – Mini Cave

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