Persistent Electro-Optical/Infrared Wide-Area Sensor Exploitation

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Project Background

- In this presentation, we provide a sampling of some results obtained with funding under Air Force SBIR contract FA8650-10-C-1709.
- The authors wish to thank R. Alan Wood, Todd Rovito, Clark Taylor, Kevin Priddy, and Mark Minardi for their helpful suggestions.
- This work is focused on development of algorithms and software for exploiting ***wide-area persistent*** EO/IR motion imagery from sensors such as Constant Hawk, Angel Fire / Blue Devil, Gorgon Stare, ARGUS-IS / IR, AWAPSS, MASIVS.

http://www.darpa.mil/uploadedImages/Content/Our_Work/I2O/Programs/Autonomous_Real-time_Ground/Images/full/ARGUS_Mission14_Poster_12-06-0920(rev1)[1].JPG

Example Wide Area Motion Imagery (WAMI) Sensor: AWAPSS

SPECIFICATIONS

Sensor type: Dual band sector scan panoramic, auto exposure, par-focalized	
Visible resolution, 20K' SR:	.75 meter
IR resolution, 20K' SR:	1.0 meter
Frames per second:	Field selectable 1 or 2 hertz
Bits per pixel:	12 Vis, 14 IR
Coverage:	68 AT x 60 XT degrees
Performance:	
Flight hours	>12,000 hrs
Visible brightness range:	50 to 8,000 foot lamberts
NEDT:	40 milli Kelvin
Persistent Image area:	8 km diameter

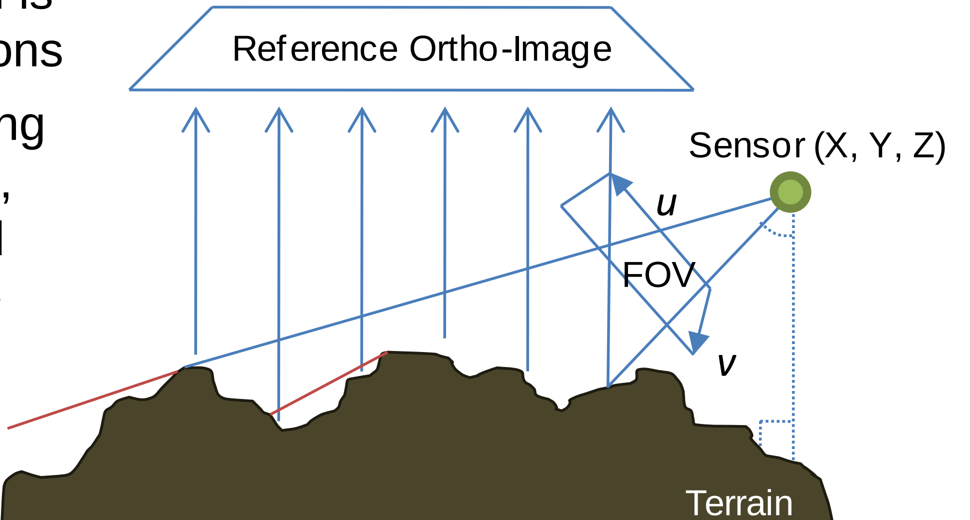
- www.baesystems.com/download/BAES.../**awapss**-datasheet
  (The content on this slide is from the above publicly available datasheet)
- Airborne Wide Area Persistent Surveillance System (AWAPSS)

21 inch (53 cm) AWAPSS Turret

11k x 8k MWR image

Enabling Effective Multi-Sensor Data Exploitation

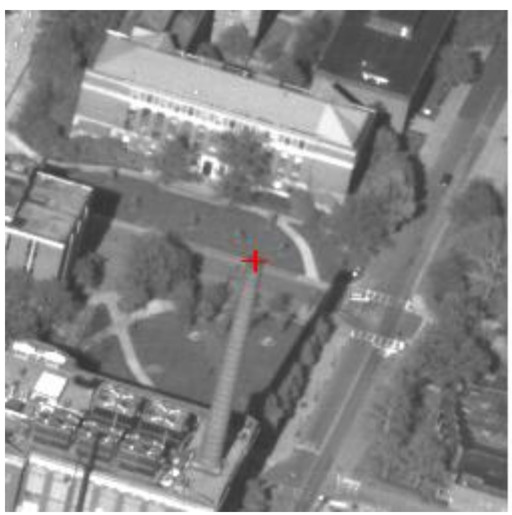
- In a Layered Sensing architecture, multiple sensors may observe a scene, providing complimentary capabilities for target identification and tracking, etc.
- Registration of multi-sensor data is necessary for effective fusion, and *geo-registration* is required for targeting and fusion of information from GIS databases.
- **Wide area** motion imaging (WAMI) sensors can provide a framework in which to register narrow field of view (NFOV) sensor data with non-overlapping coverage.
- Geo-registration of EO/IR imagery typically includes errors of many tens of meters due to orientation errors combined with long sensor-scene ranges, as well as other metadata errors, including sensor parameters and time synchronization.
- EO/IR imagery-based geo-registration is challenging due to perspective variations
- The **persistent** nature of WAMI sensing enables construction of scene models, based on perspective diversity around complete orbit(s), with constant scene coverage. 3D scene models enable WAMI and NFOV geo-registration.



EO/IR Sensor Auto-Calibration

- To effectively utilize persistent imagery collection, e.g., for 3D model reconstruction, the relative poses of the sensor, over time, must be known.
- We have developed a loop-closing joint bundle adjustment algorithm to achieve very accurate estimation of *relative* positions and orientations of cameras over time:
  - Goal is *relative* imagery geo-registration error ~1 m around a full WAMI orbit
  - Based on breakthrough in perspective-corrected image feature extraction and matching followed by sparse bundle adjustment (optionally, multiple bootstrapped iterations)
  - We have demonstrated joint internal and external (including biases) estimation

Sensor Metadata



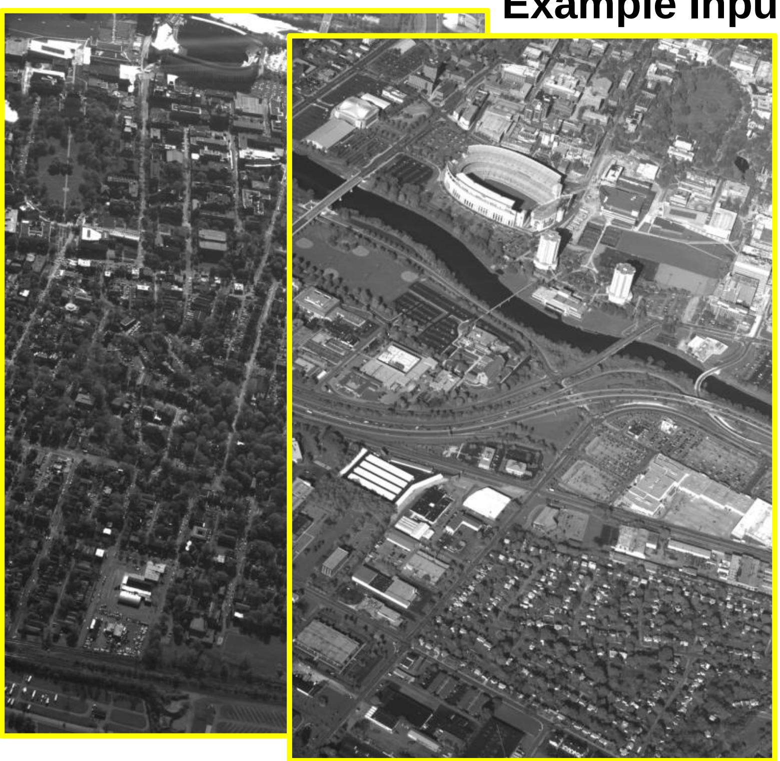
Optimized

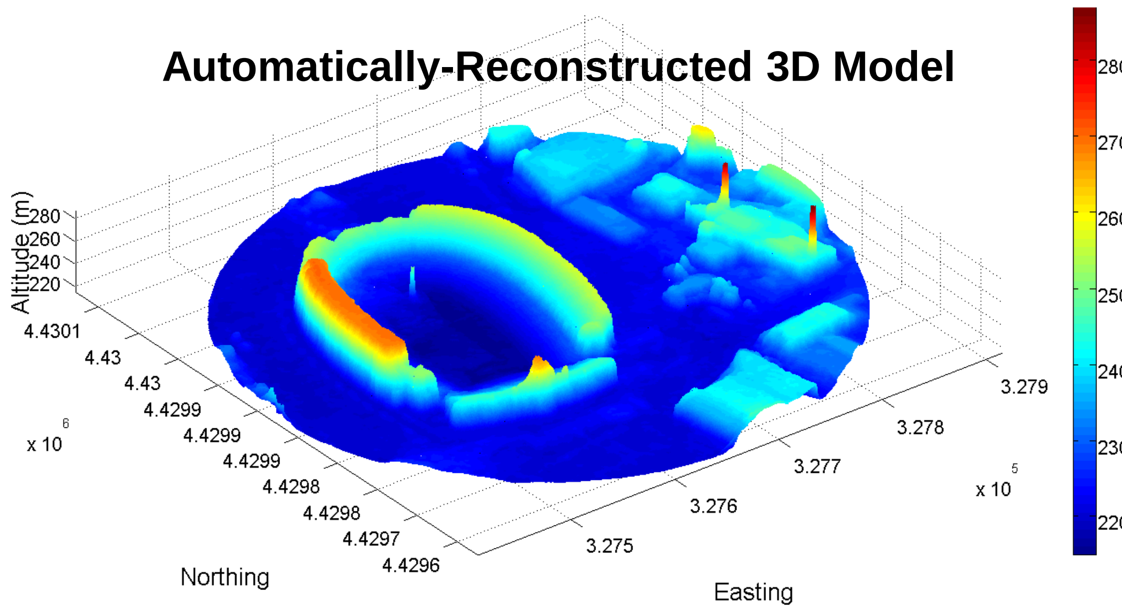
CLIF 2006 Public Release Imagery

Fully-Automated 3D Reconstruction

- Accurate modeling of initial and intermediate reconstruction ambiguities due to occlusion effects and low-texture/homogeneous-intensity regions (the algorithm accurately reconstructs these surfaces after processing multiple frames of data).
- Completely *dense* 3D point reconstruction at *pixel-level resolution*
- Well-suited to massively-parallel implementation in low-cost CPU/GPU
- Triangular mesh 3D surface model estimation, and *generation* of DTED, DEM, etc.

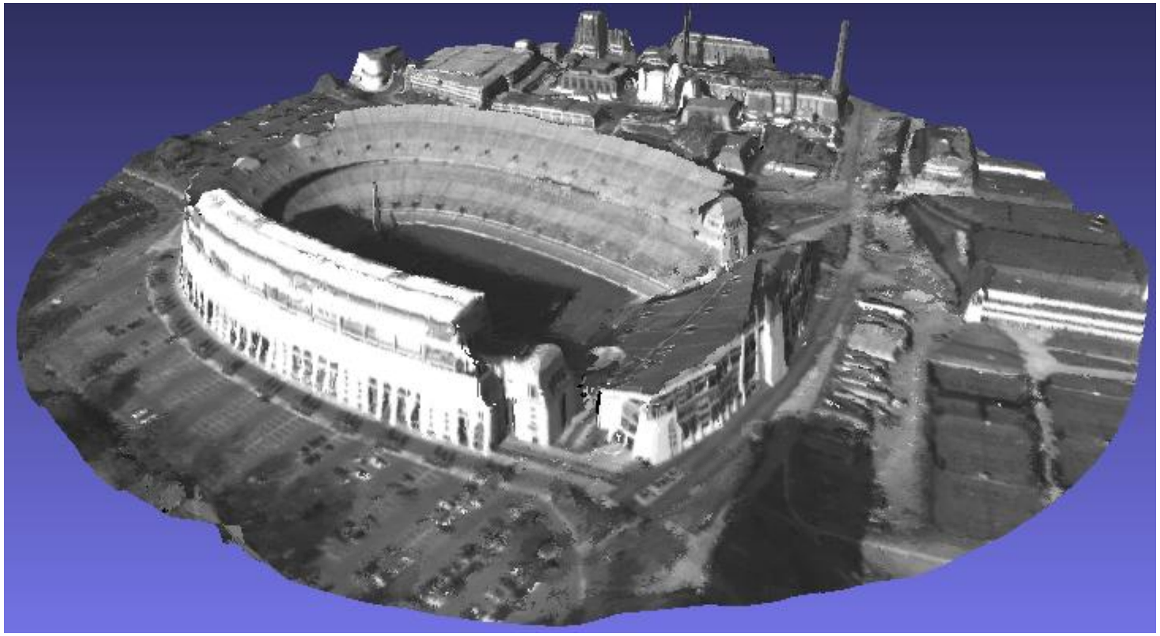
Example Input Images

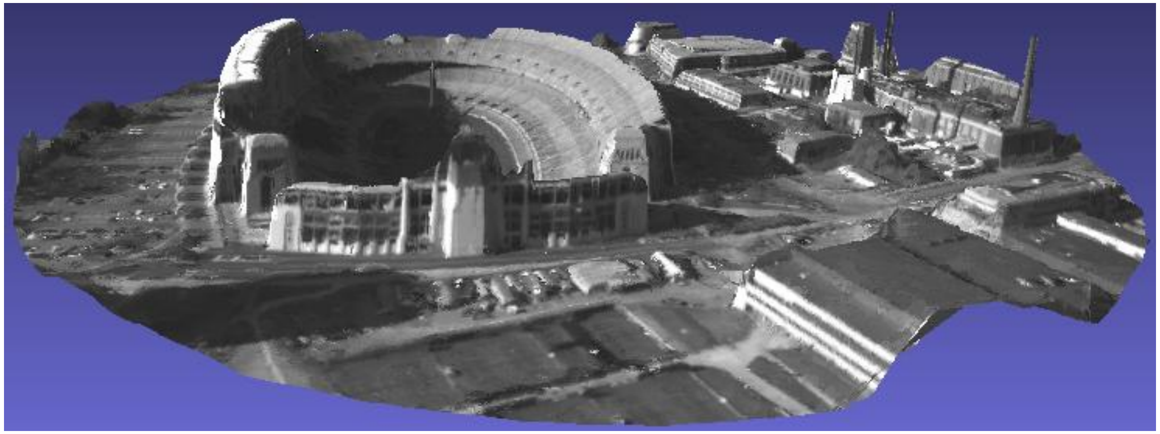




Formed from 1 complete orbit ~ 900 frames

Textured PLY Model (Demo in MeshLab)





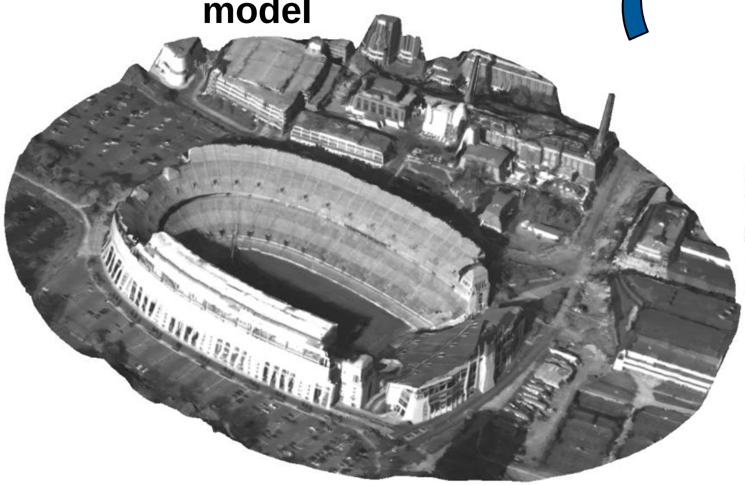
Imagery Perspective Correction

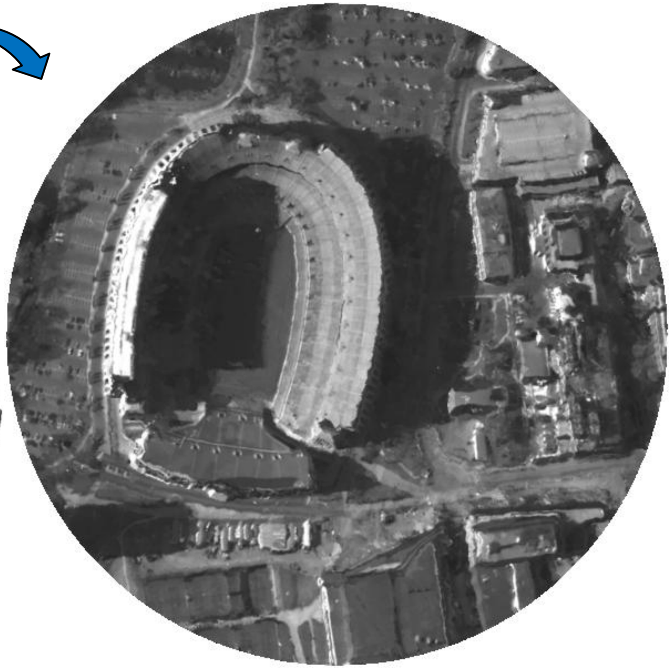
- In many cases, only 2D reference maps (e.g., satellite ortho images) are available
  - Geo-registered reference map creation is expensive, and requires human-in-loop supervision and/or intervention
- Using a reconstructed 3D model and EO/IR images from multiple perspectives, a texture model of the 3D surface can be estimated and rendered to any perspective, enabling more accurate alignment with a 2D reference map.

Render to orthographic perspective

Auto-align with reference map

3D view of a textured reconstructed surface model

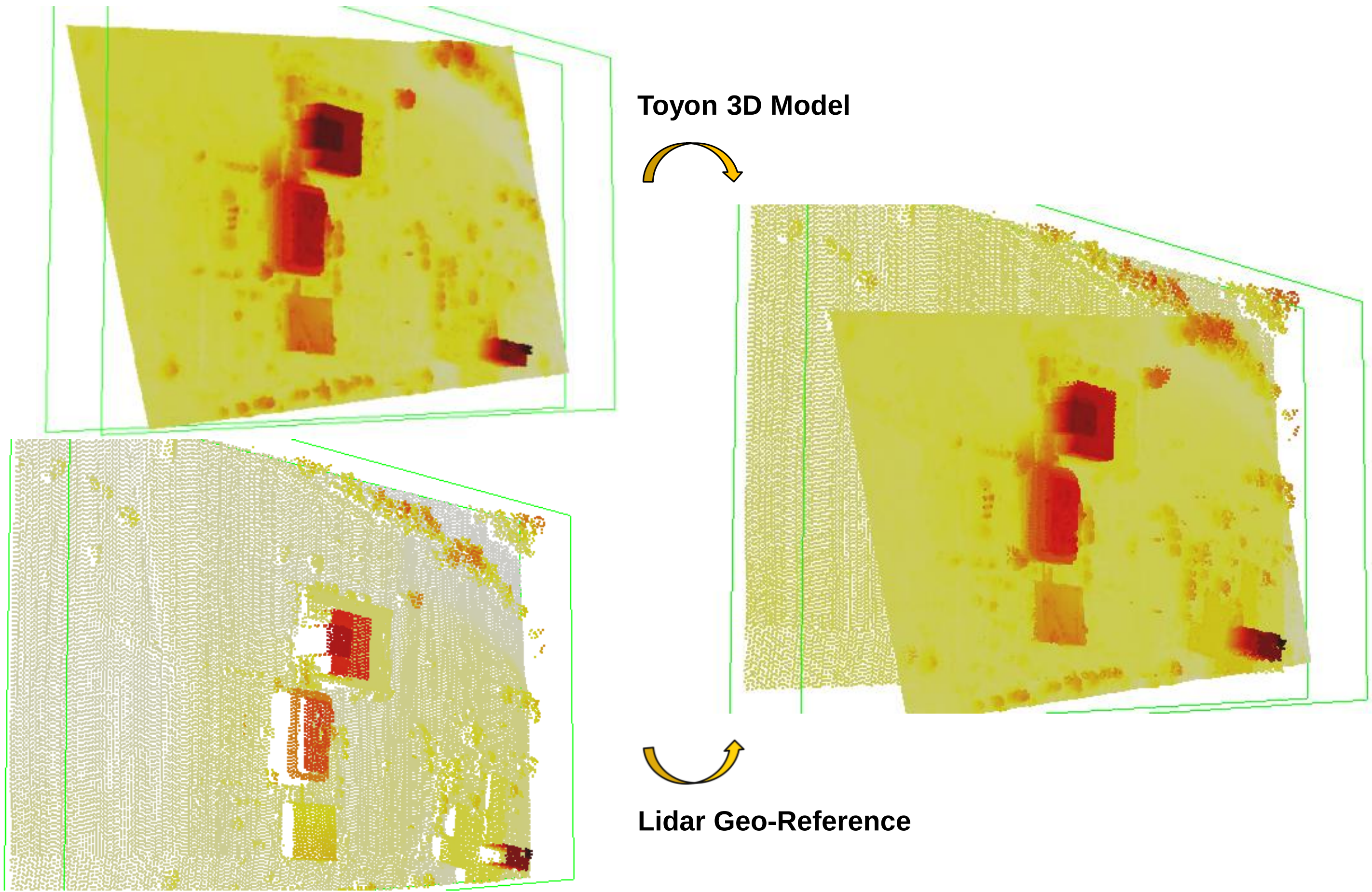




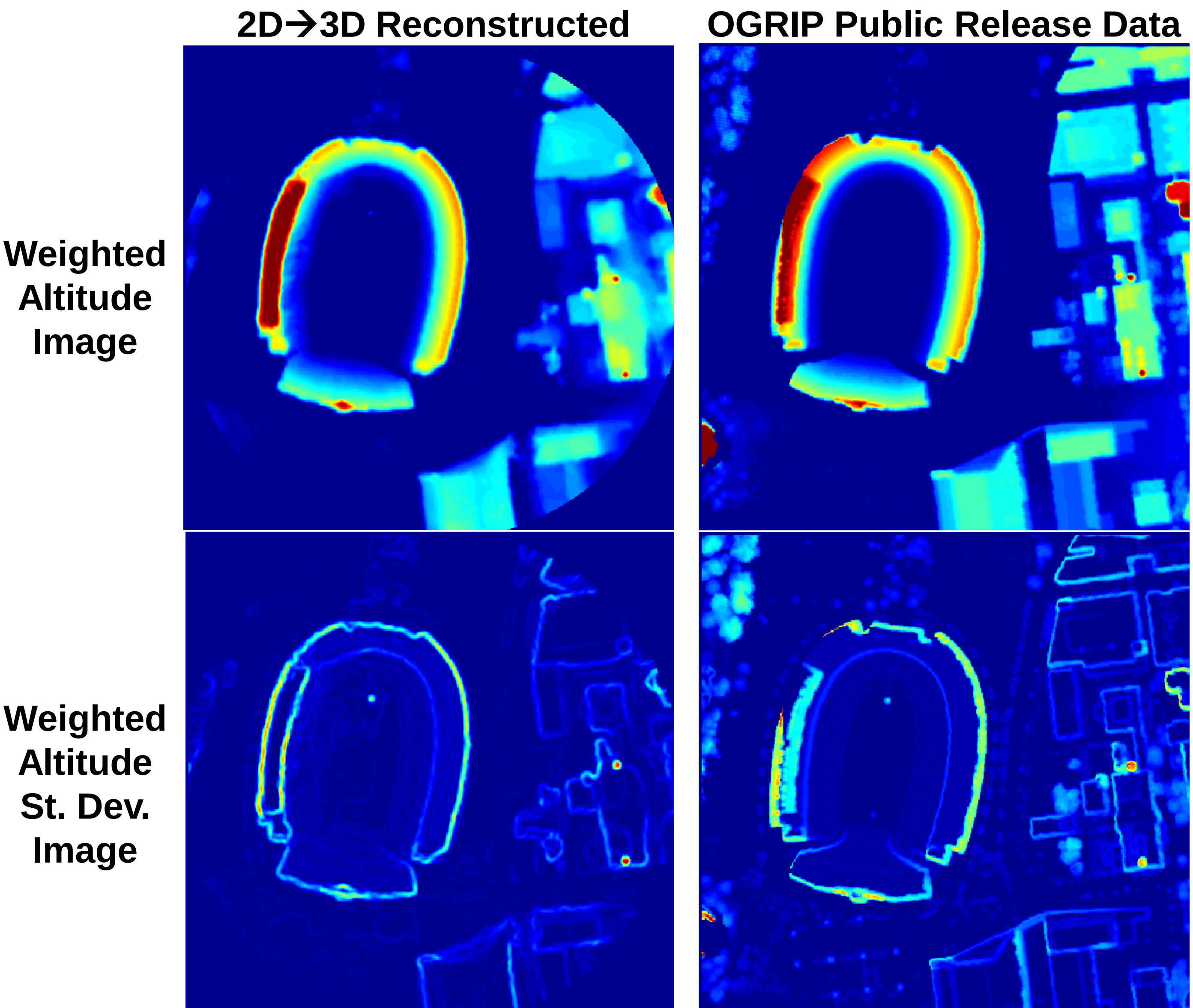
2D reference map

3D-to-3D Geo-Registration

- Direct 3D-to-3D registration removes difficulties due to multi-sensor intensity variations, and significantly reduces difficulties due to multi-sensor perspectives
- Remaining challenges include resolution and model completeness variations



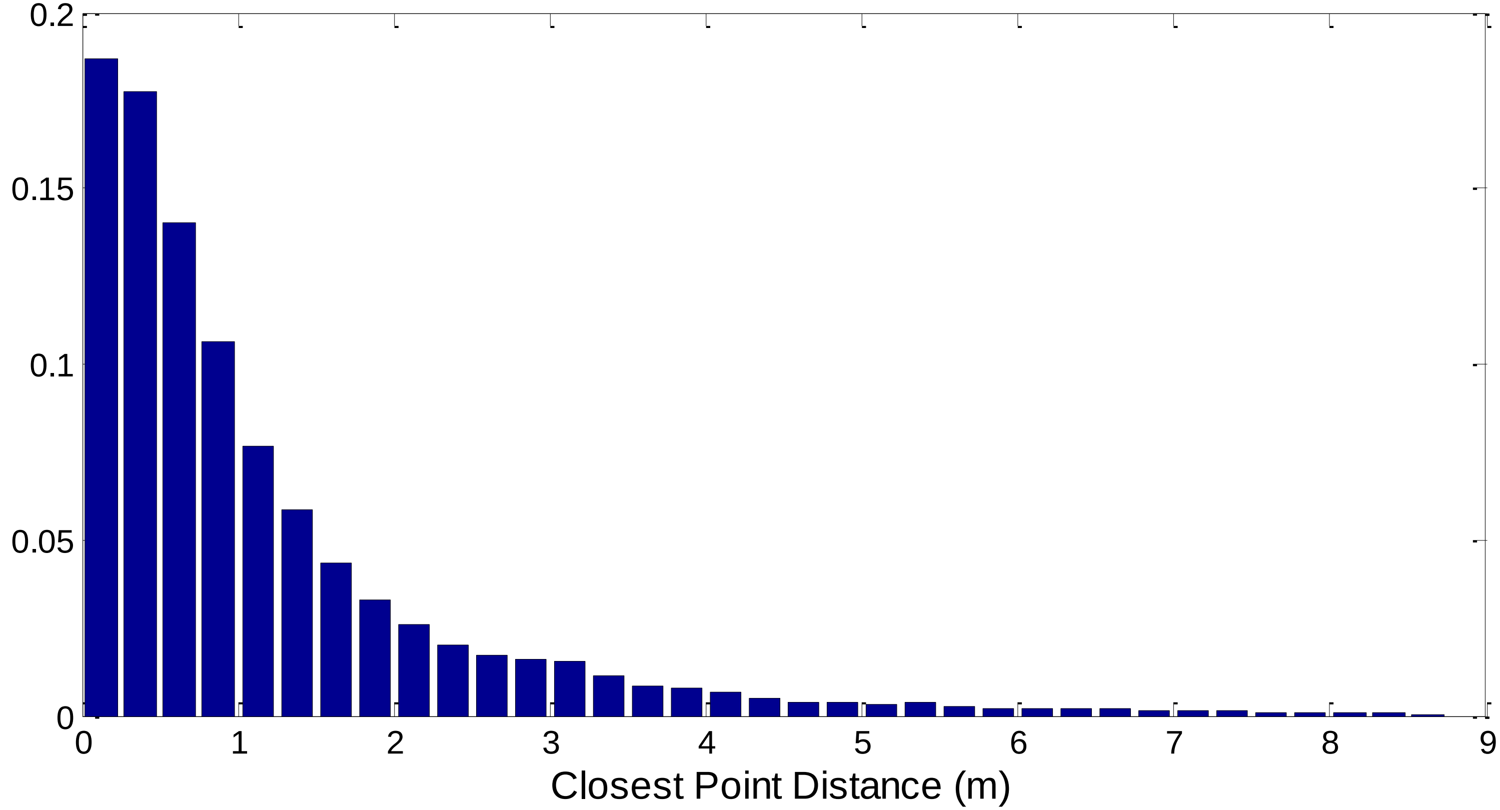
Efficient, Robust Model Alignment



- Efficient coarse-to-fine registration optimization proceeding from 2D translation only to 2D translation, rotation, and scale
- Mutual information-based registration metric provides robustness to model differences and enables effective decoupling of altitude alignment, significantly decreasing run time
- Final altitude alignment minimizes mean altitude differences

Statistical Performance Assessment

- Minimum distances from 55,000 LIDAR points to the reconstructed triangular mesh 3D surface model were measured, and a histogram formed
- Mean and median errors: 1.26 m and 0.74 m (small compared with 7-ft LIDAR point spacing

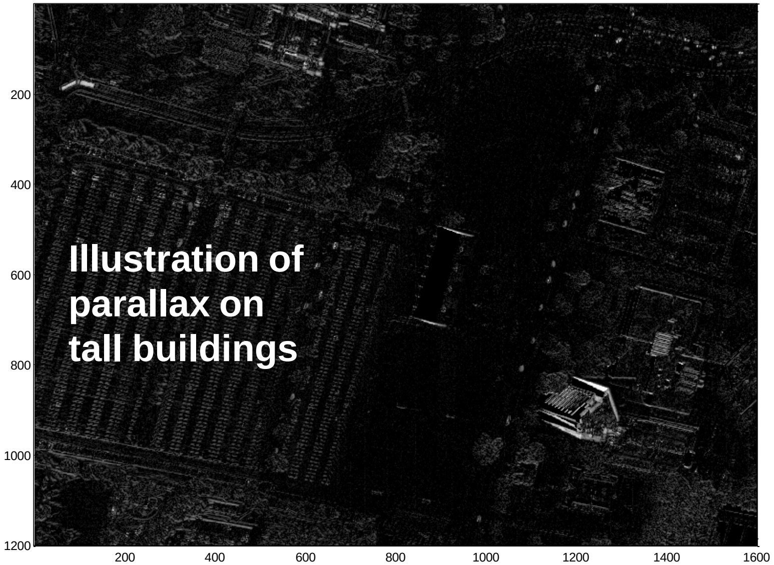


Moving Target Detection: The Parallax Problem

- *Parallax*: stationary objects at different ranges from the sensor move at different rates in the image plane
- In moving target detection processing, parallax effects are most difficult to mitigate when the altitudes of objects differ greatly: e.g. tall buildings or trees
- In past work for DARPA and SOCOM, Toyon developed real-time software for improved parallax mitigation based on 2D image processing
- To optimally mitigate parallax effects, a 3D scene model is required

Portion of CLIF 2006 frame

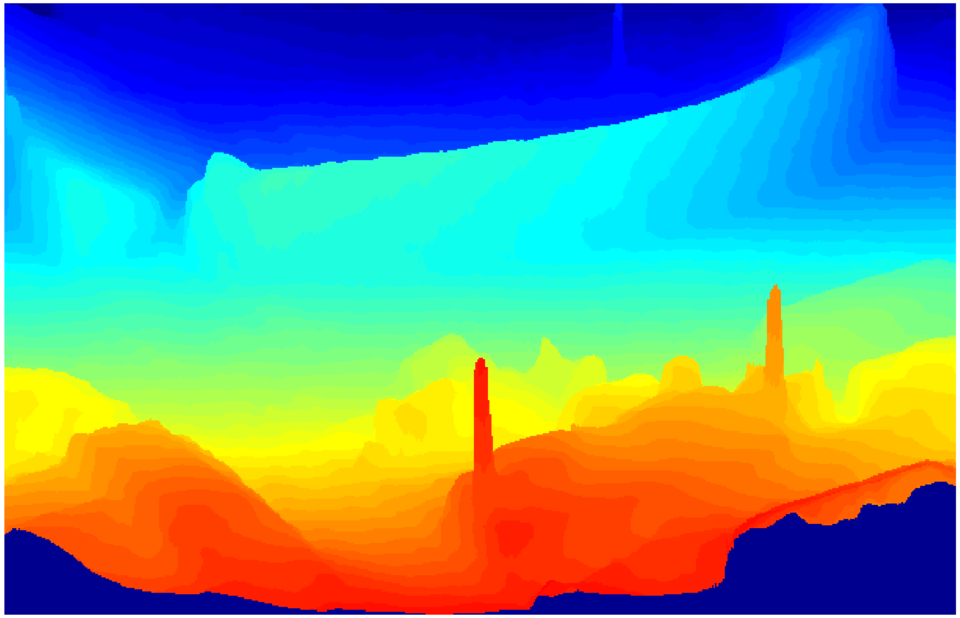
Planar homography-registered frame difference (no parallax mitigation)



Parallax-Mitigated Moving Target Detection: Example Result

- By performing statistical background modeling for clutter (e.g., glint) suppression in a geo-registered 3D model framework, registration of the model with the current frame is enabled via projecting into the current frame, providing ***optimal mitigation of parallax*** in frame-to-frame registration.

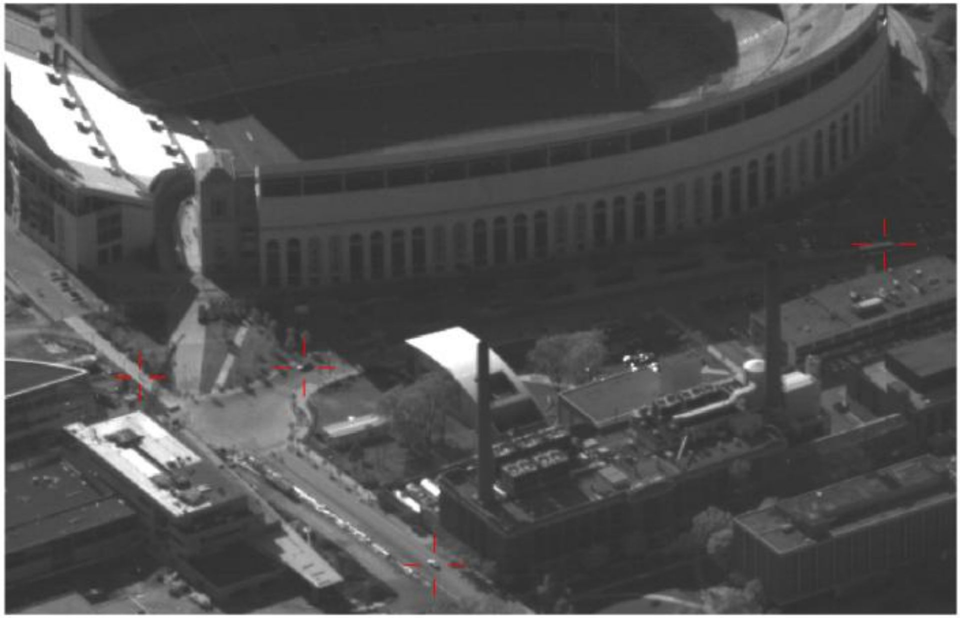
Blue: longer range **Depth map**



(dark blue: border of modeled region)

Red: closer range

Detections displayed on raw frame



Cross hairs: dismount and 3 vehicles

Applications of Fully-Automated 3D Modeling / Discussion

- Image geo-registration
- Multi-sensor registration
- Parallax mitigation in target detection
- Context-based target tracking
- Improved target geo-location
- Battle damage assessment
- 3D change detection
- Sensor resource management (e.g., line-of-sight checks)
- Route-planning/obstacle avoidance for low-flying small UAVs

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