Pixel-Level Fusion of Active/Passive Data for Real-Time Composite Feature Extraction and Visualization

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Space Dynamics Laboratory/Utah State University

ABSTRACT

System Concept

A system has been developed whereby active LADAR and passive imaging data are registered in hardware at the pixel level. For the sake of discussion, the sensor is herein called a "LADAR/EO pixel-level Fusion Sensor" or LEFS. This sensor produces structural and spectral data embodied in one dataset, permitting composite feature extraction and visualization.

The combined use of LADAR and passive EO/IR data has well known synergism. Our system fuses these two data types in a novel way such that real-time performance is possible. This significantly enhances the ability to quickly and correctly identify targets.

By fusing the range data from the active sensor with the pixel-registered imagery, registered 3D images are available in real time (Figure 1). Each pixel is coded with full spectral information combined with structural information obtained by the active system (Figure 2). The resulting fully aligned high-dimension feature vector enhances target recognition and permits dense point matching for precise image mosaicking.

A significant benefit is in combining the ability of pencil beam active systems to work at long ranges and to penetrate obscurants with the passive array's wide instantaneous field of view at increased resolution. One application in which this has had enormous benefit is in observation through partial or intermittent obscuration; e.g. with partial cloud cover or foliage. Reflected radiation associated with features within gaps in the obscuration are sensed passively while at the same time the active pencil beam efficiently maps structure within the revealed region (Figure 3). Pixel-level registration of data permits extended regions to be mapped by combining temporally or spatially diverse collections (Figure 4).

Applications

Military application for which this technology is being developed or assessed include precision tactical targeting, Precision Controlled Reference Image Base (CRIB) production and Automatic Registration of targeting data into the CRIB.

Civil applications include 3D city modeling, real-time airborne mapping, post-disaster reconnaissance, floodplain and coastline mapping, drug interdiction target detection, environmental monitoring, and search and rescue.

Paper presented at the RTO IST Workshop on "Massive Military Data Fusion and Visualisation: Users Talk with Developers", held in Halden, Norway, 10-13 September 2002, and published in RTO-MP-105.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **00 APR 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE
Pixel-Level Fusion of Active/Passive Data for Real-Time Composite Feature Extraction and Visualization

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Space Dynamics Laboratory/Utah State University

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001665, RTO-MP-105 Massive Military Data Fusion and Visualization: Users Talk with Developers., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**34**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Visualization Implications

Such detailed three-dimensional multi-spectral data present challenges and opportunities for visualization.

The multispectral character of the data presents the familiar problem of presenting high dimensional data. Adaptive use of false colors is the most obvious approach. In the case of an LEFS system, the false color scene is wrapped into a 3D structure.

The opportunity to recover range-tagged feature data through partial or intermittent obscuration permits partial 3D scene reconstruction. The use of multiple viewpoints enables the filling in of the inevitable residual shadowing associated with a given viewpoint. One potential visualization technique is that of selective layering. Using this technique, the analyst is able to scan or step through layers of the data, either in the range dimension or in a dimension contoured to modeled terrain. In this way, for example, the analyst can explore the scene at or near ground level by suppressing the intervening cloud or foliage obscuration. Alternatively, he can isolate aircraft or other objects from an earth background.

A very high degree of compensation for motion in the sensor platform is achievable because the precise range is obtained from the LADAR at the same time the fully registered precise angle data from the passive optical system is collected. This eliminates the parallax problems encountered by passive systems alone. Thus passive images can be automatically co-registered as proved by a prototype LEFS system at Utah State University. Figure 5 shows an example of an automatic image mosaic reconstructed on-the-fly using the wire-frame surface structure derived from LADAR shown in Figure 6. The vantage point of the viewer of these Figures happens to be above and to the left of the point from which the data was collected. Such virtual positioning is possible only because of the 3D nature of the database. Shadows in the figure are regions that were blocked from the view of the instruments, where no data could be collected. The linear seam on the right side of the lower image indicates the boundary between two adjacent digital camera shots. Brightness was deliberately increased in the image on the right of the seam to help locate the seam. Note how perfectly the two images are knitted together because of the georegistration of the data.

Ultimately a full tomographic capability could be provided. Such may have applications in dense, complex three dimensional scenes as might be encountered in urban environments. For example, it should be possible to construct detailed imagery or video of individual vehicles or people as they move through crowded streets, which intermittent blockage by other vehicles or people, buildings, etc.

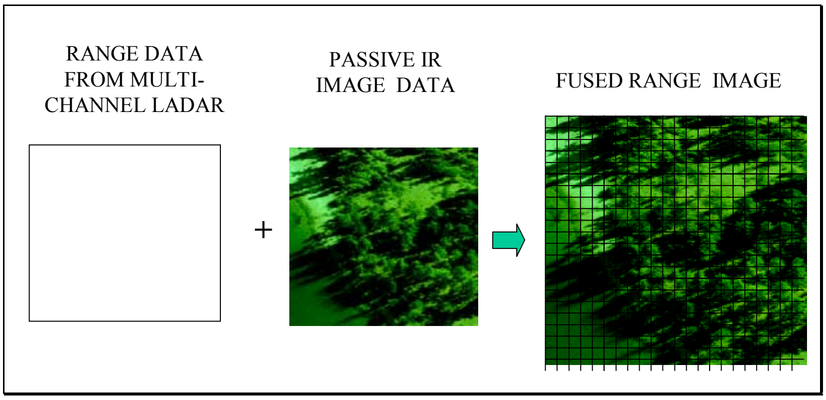

Figure 1. Hybrid 3D Image via Pixel-Level Registration

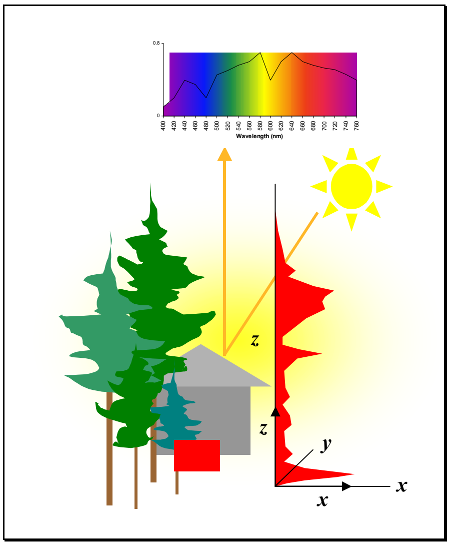

Figure 2. Pixel-Level Spectral and Structural Feature Set

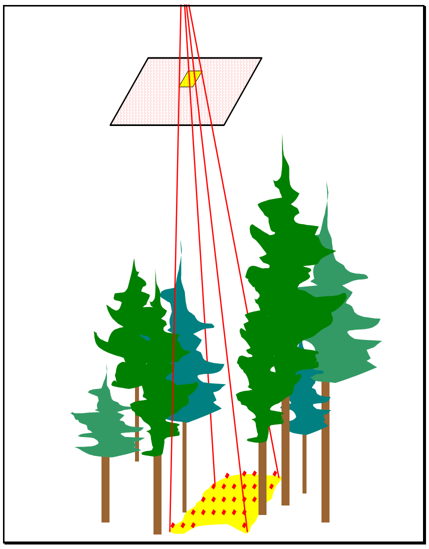

Figure 3. Observation through Partial Obscuration

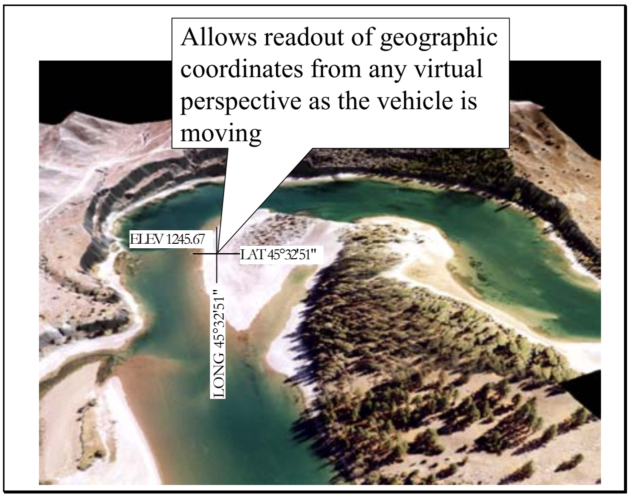

Figure 4. Large-scale image fusion

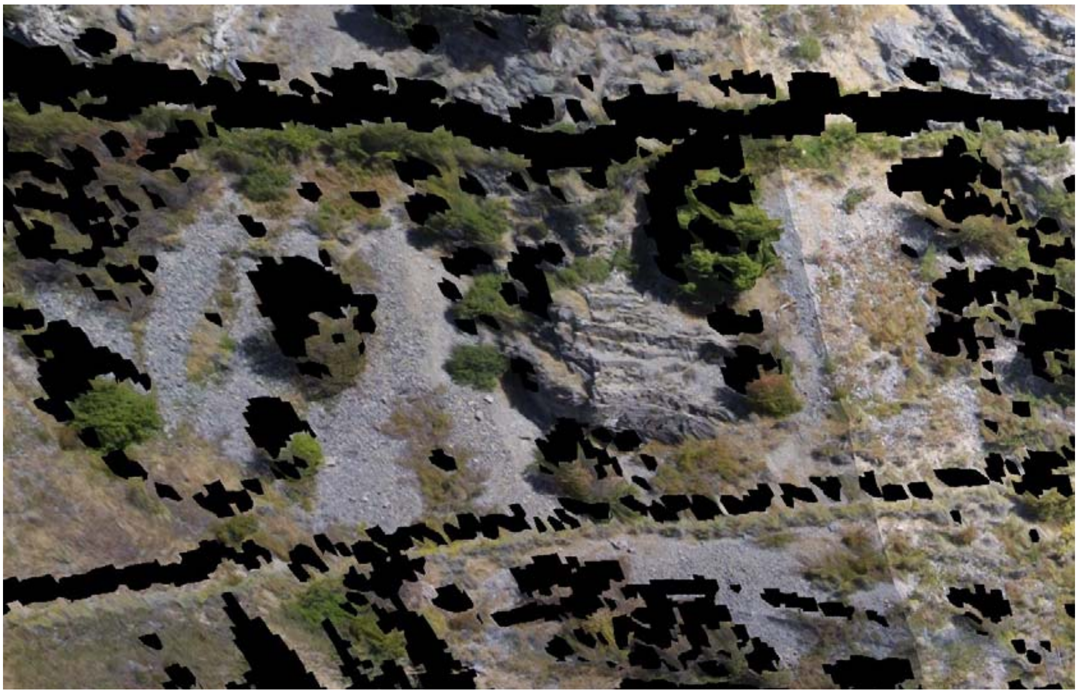

Figure 5. 3D images mosaicked using LADAR data shown in Figure 6. Note the seam defined by two images of differing brightness.

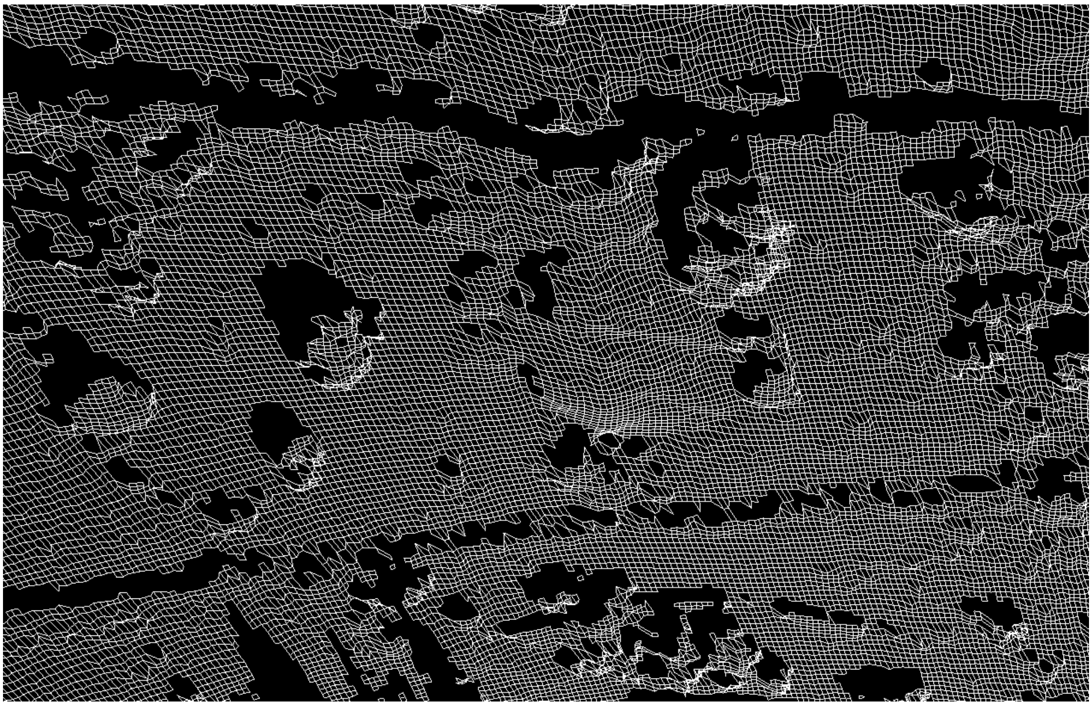

Figure 6. Wire frame constructed from LADAR data

SYMPOSIA DISCUSSION – PAPER NO: 12

Author's Name(s):

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Robert Pack, Space Dynamics Laboratory/Utah State University, USA

Question:
Range data and image data were precisely rectified in this application. How difficult is it to merge data from different platforms?

Author's Response:
The ability to co-register data sets is more straightforward if you have the same sensor types. With different sensors it is difficult to have such a precise correlation.

Comment:
You can see how knowledge evolves over time by observing and understanding the estimate of knowledge over time.

Comment:
By running the contour map of sensor performance back over a period of time you can see your ability to observe or be observed.

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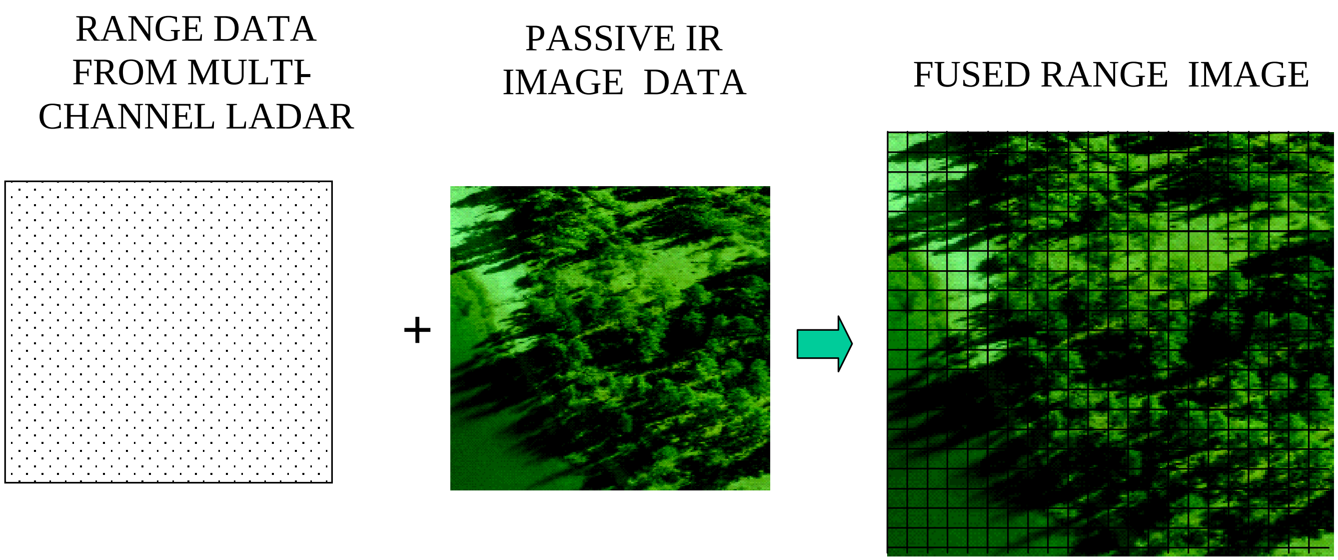
Presented at
NATO IST-036/RWS-005
Halden, Norway

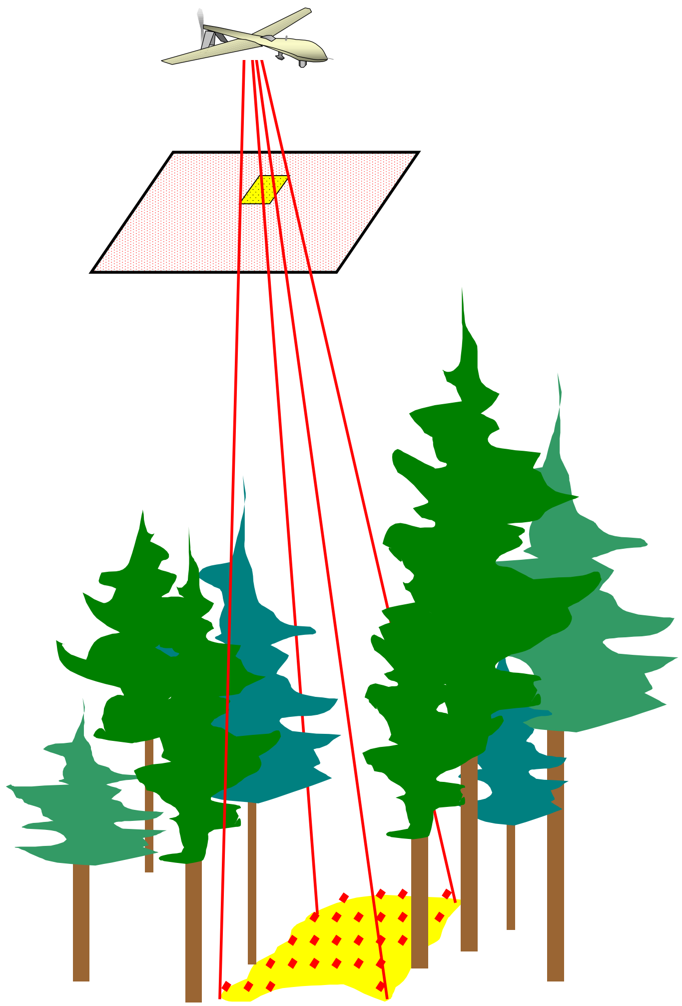
10-13 September 2002

Concept of Pixel-Level Fusion

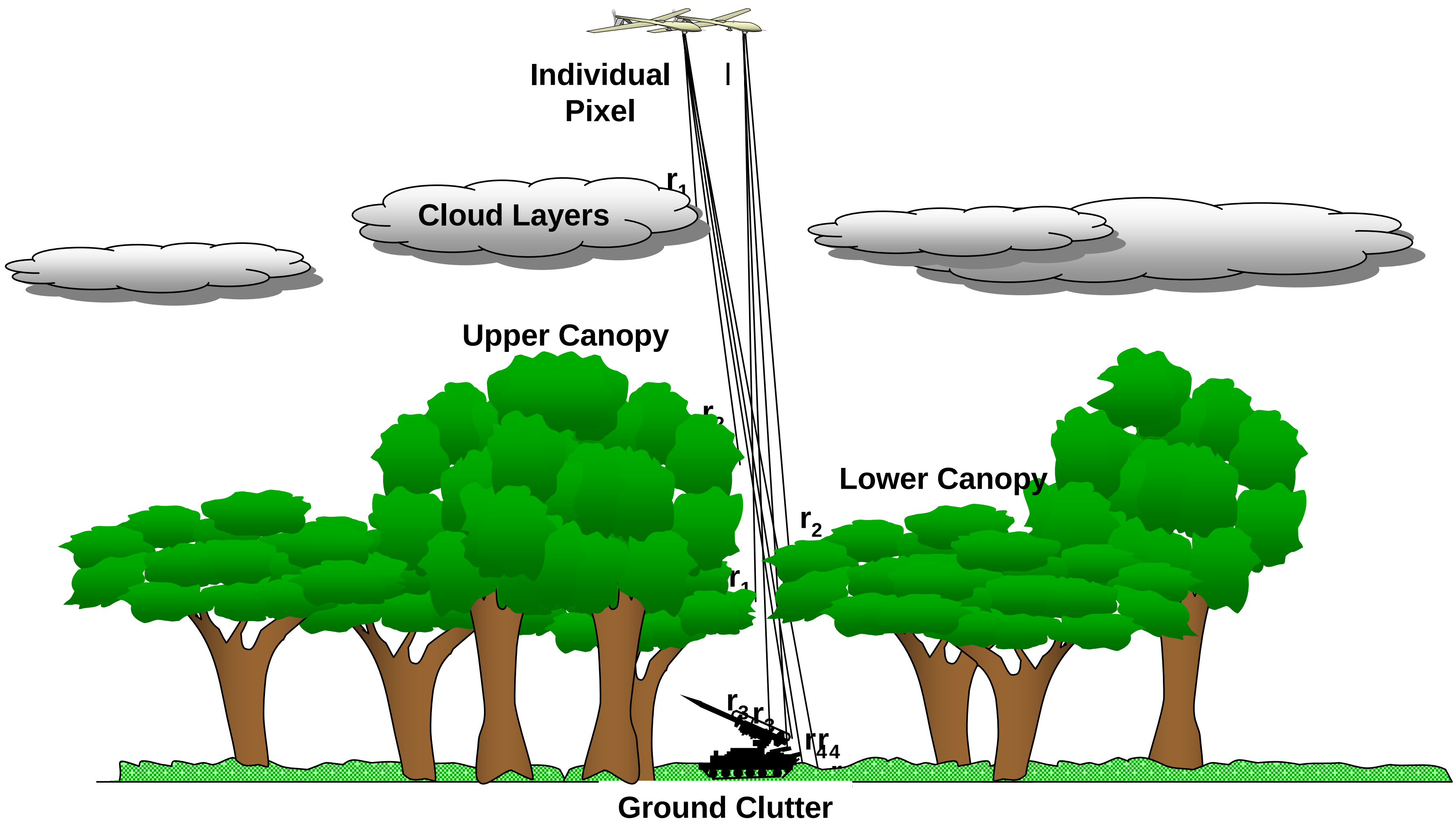
- **Active Sensor – LADAR**
- **Passive Sensor – Electro-Optic (EO) Radiation**
- **Fused into One Data Set**



Enables Observation Through Partial Obscuration

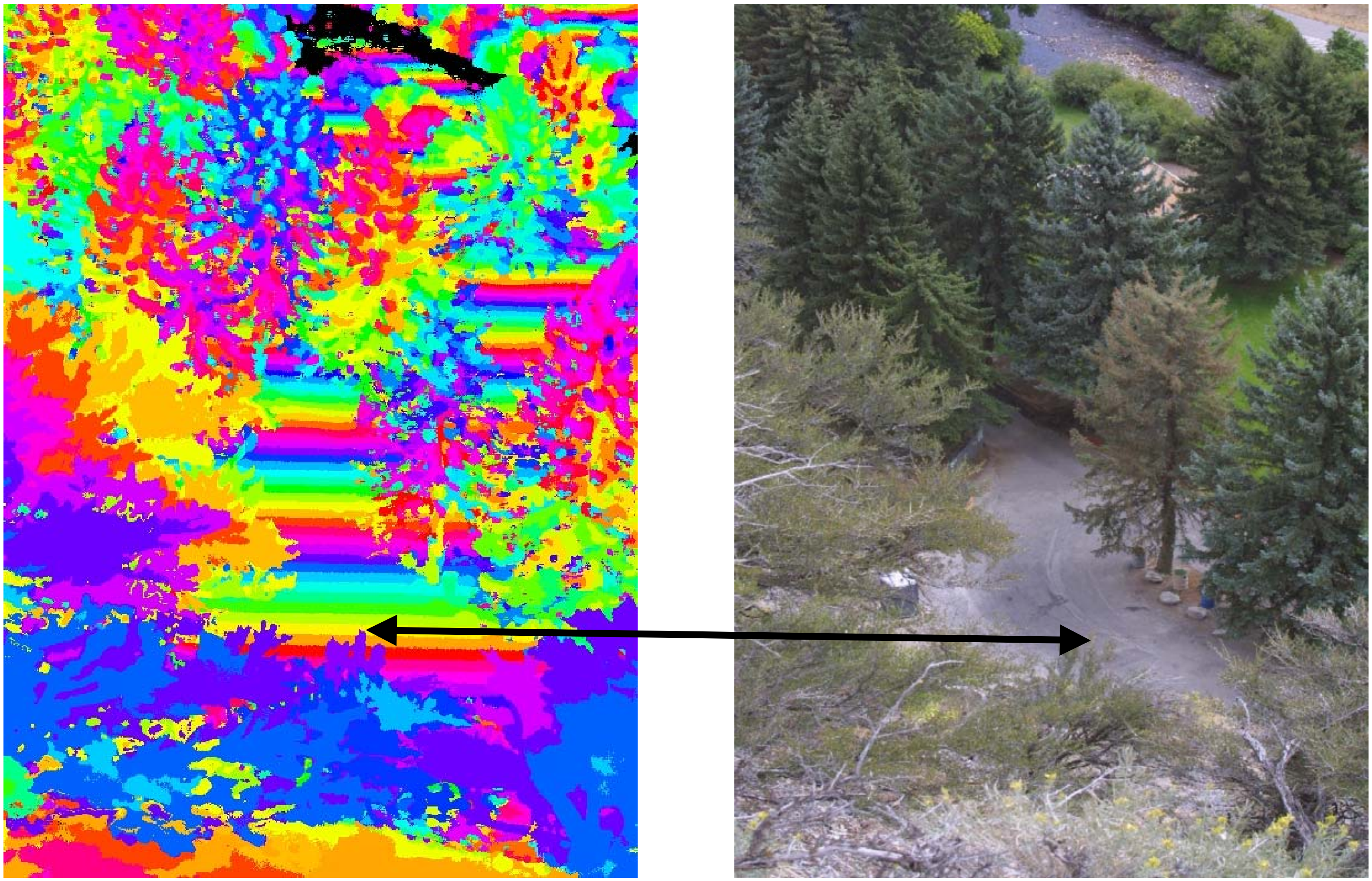


Employment Concept



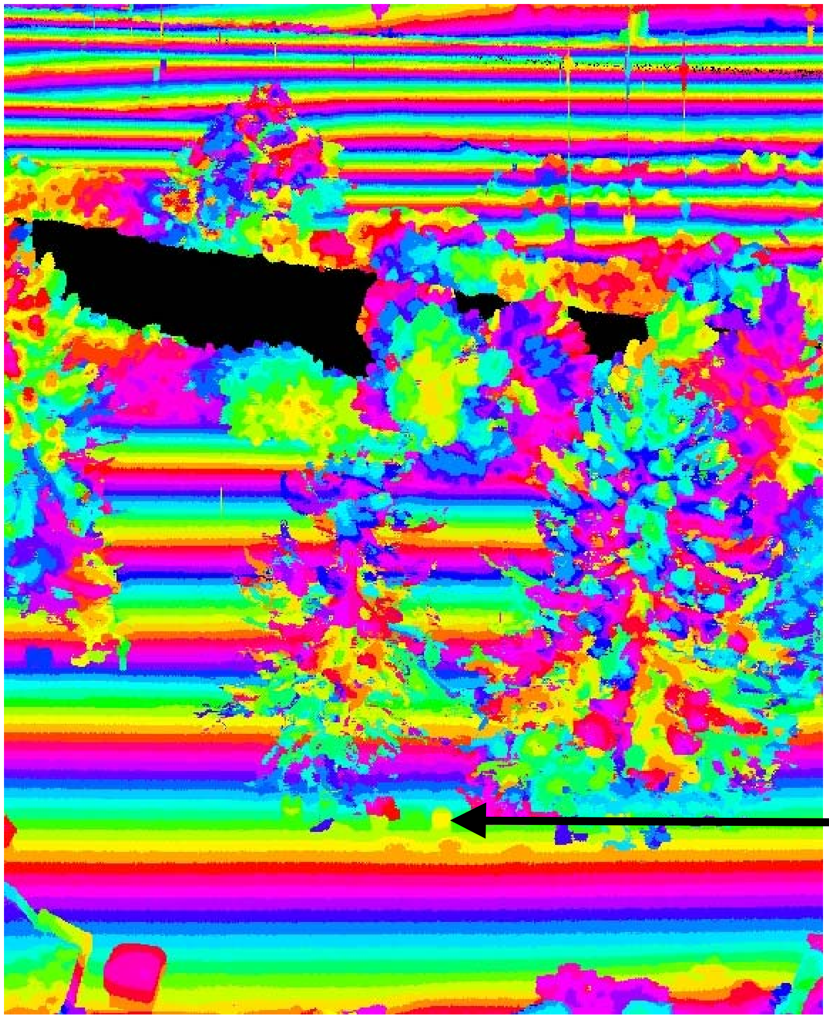
Fused LADAR/EO Image 1
(Co-Registered and Georeferenced at the Pixel Level)

LADAR Image **EO Image**

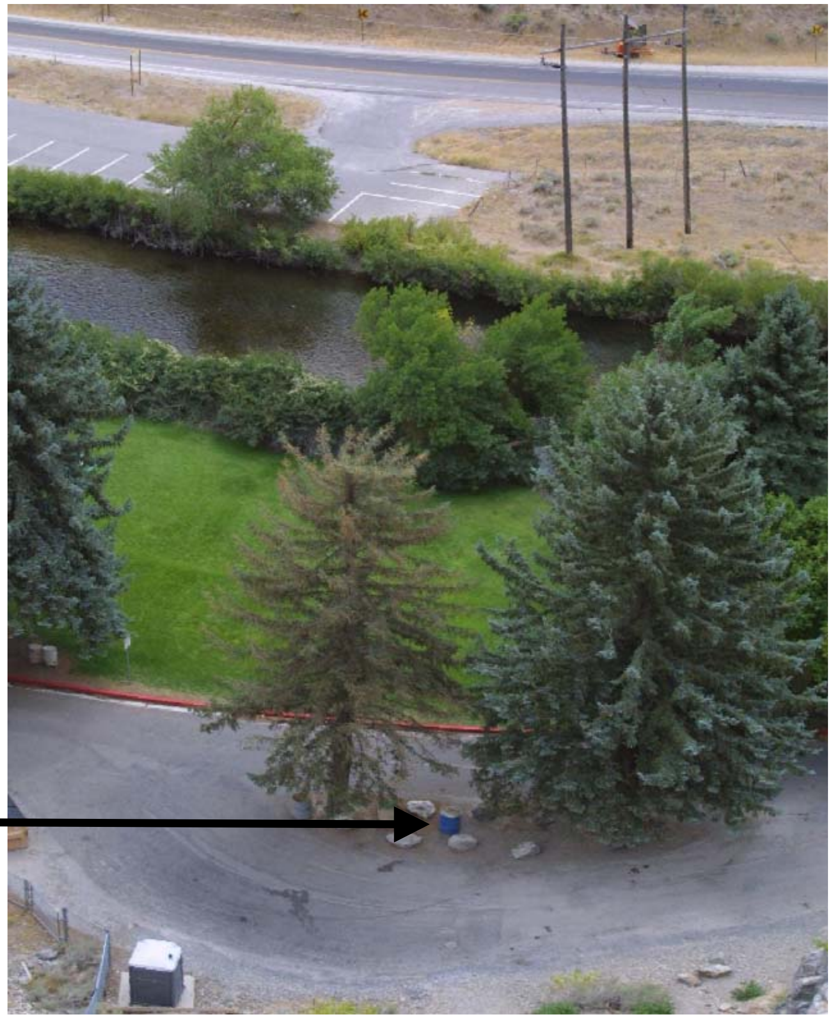


Fused LADAR/EO Image 2
(Co-Registered and Georeferenced at the Pixel Level)

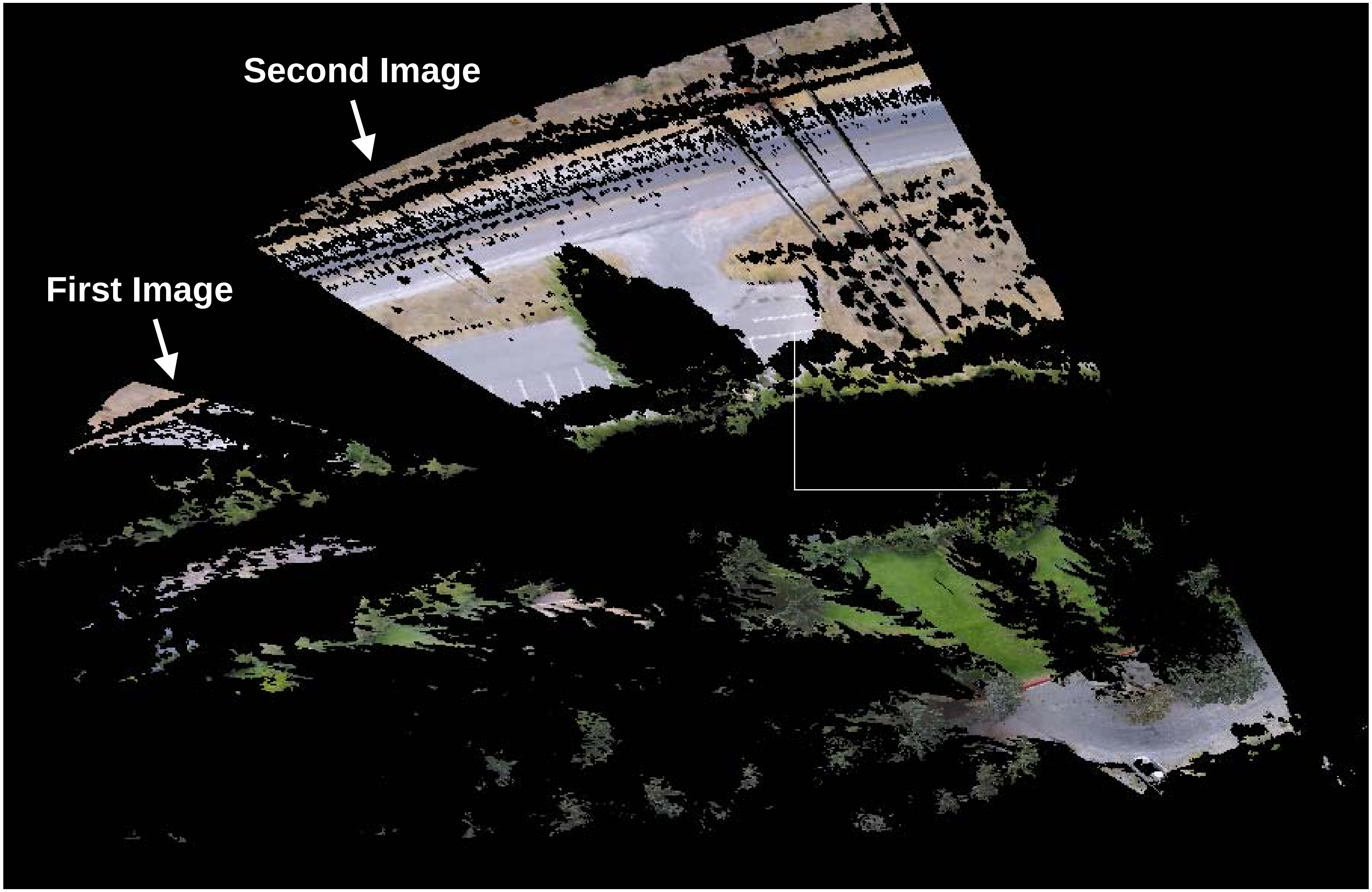
LADAR Image



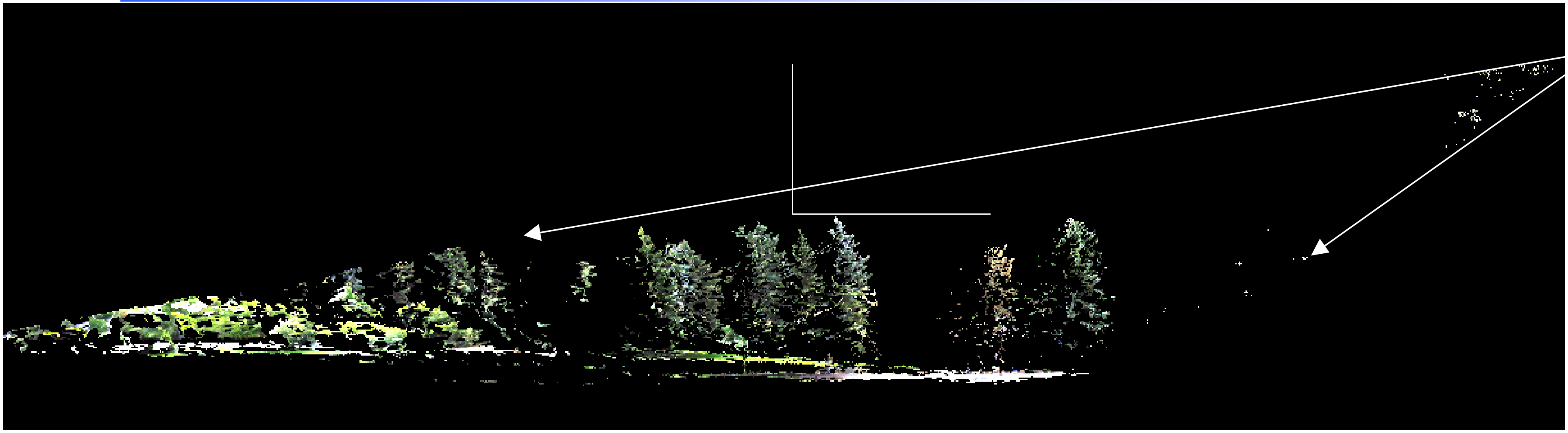
EO Image



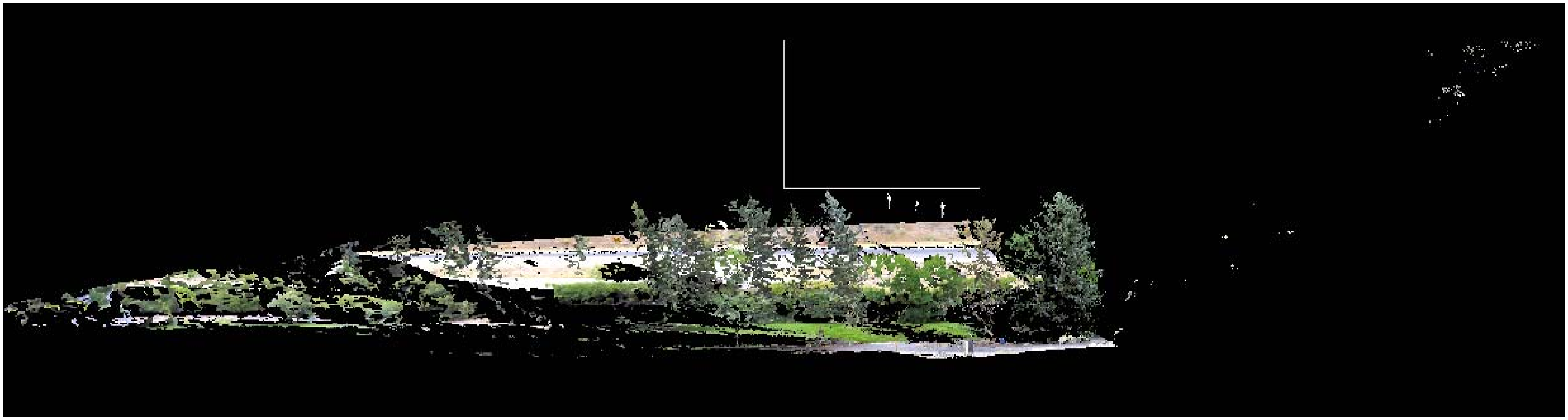
Orthoprojection of the Two 3D Images Combined in Geographic Space



Profile Views in 3D Viewer



First LADAR/EO Image

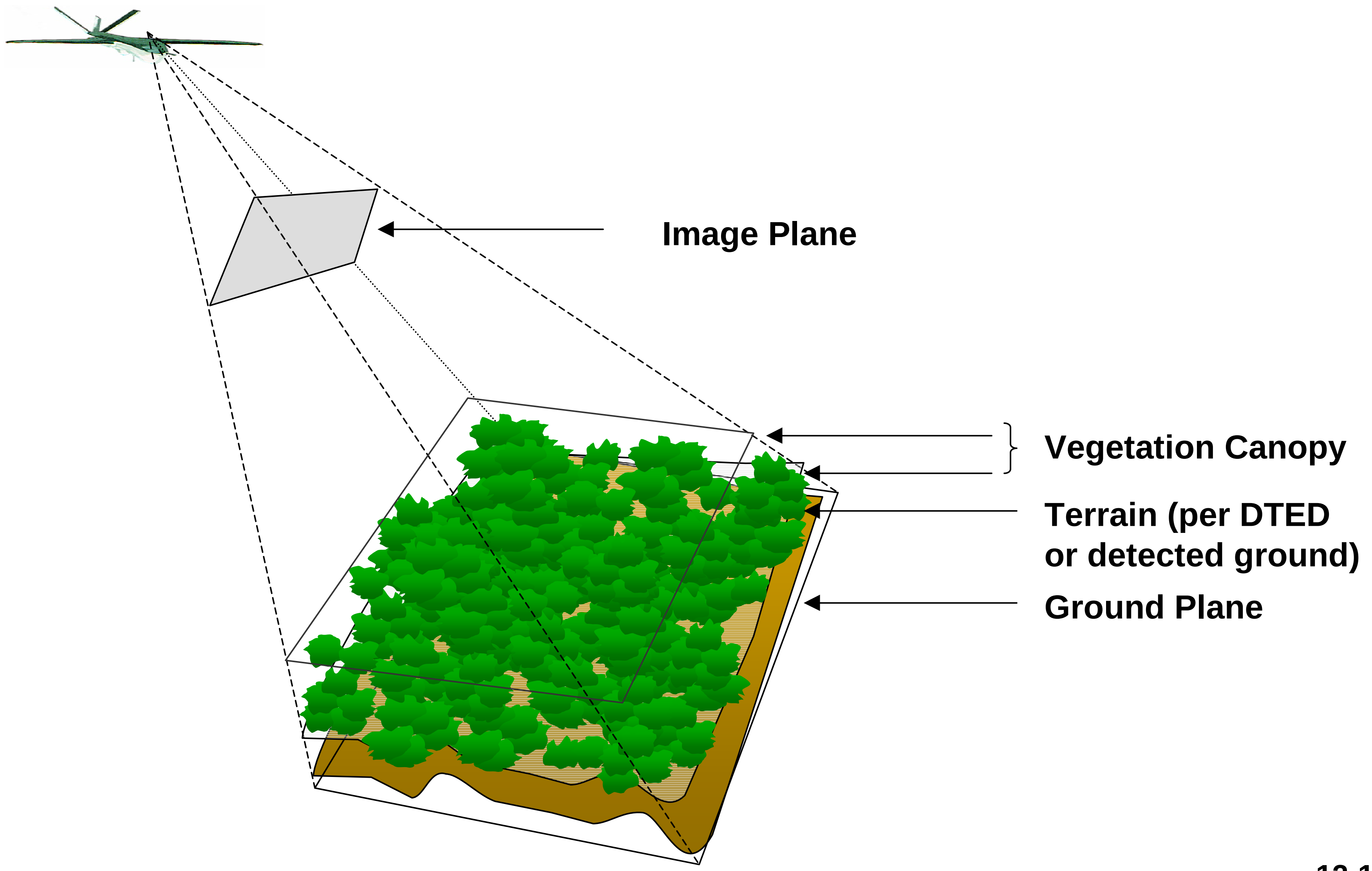


First and Second LADAR/EO Images Combined

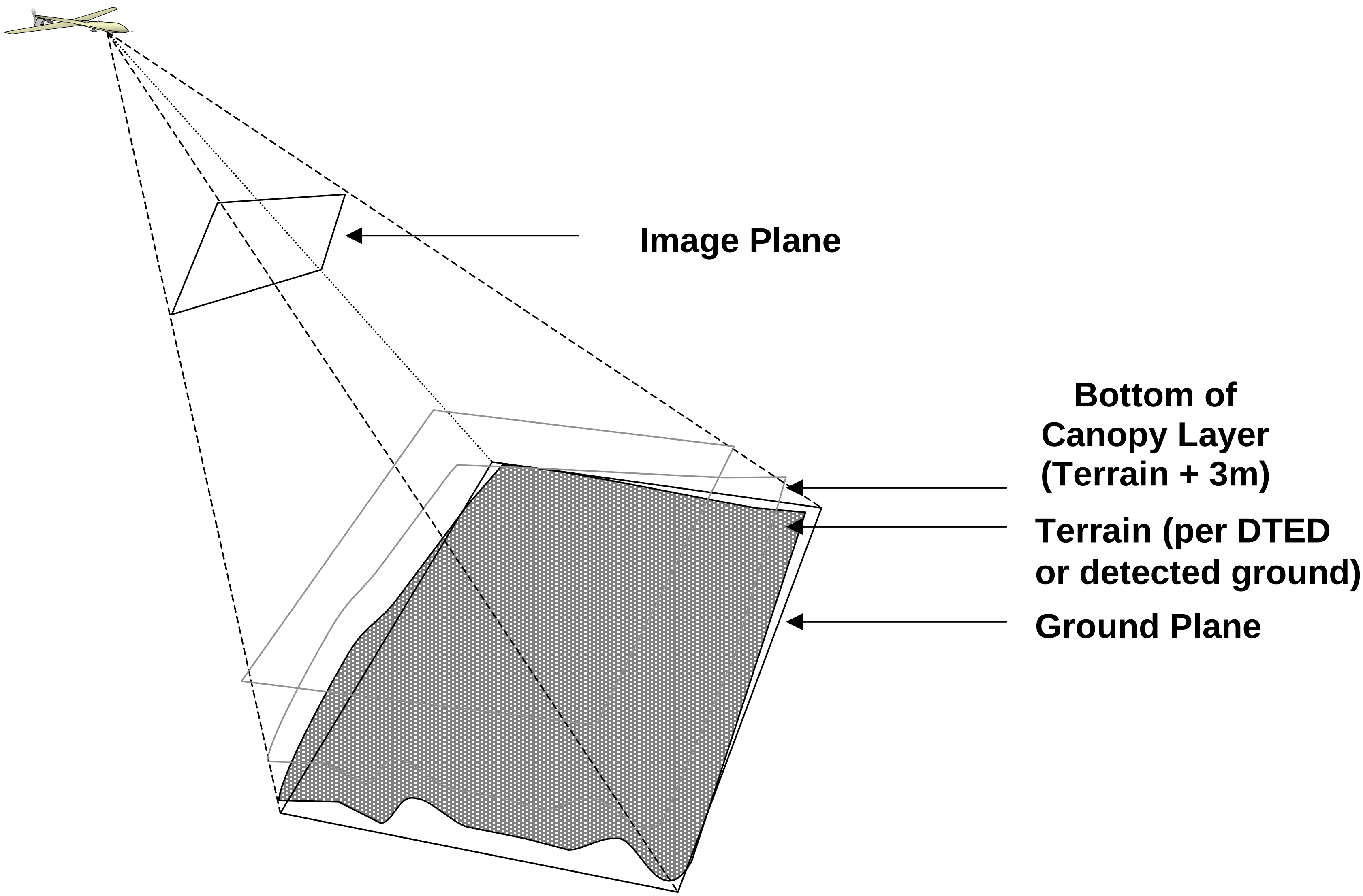
Visualization Concept -

Data Volume Exploration and Clutter Removal

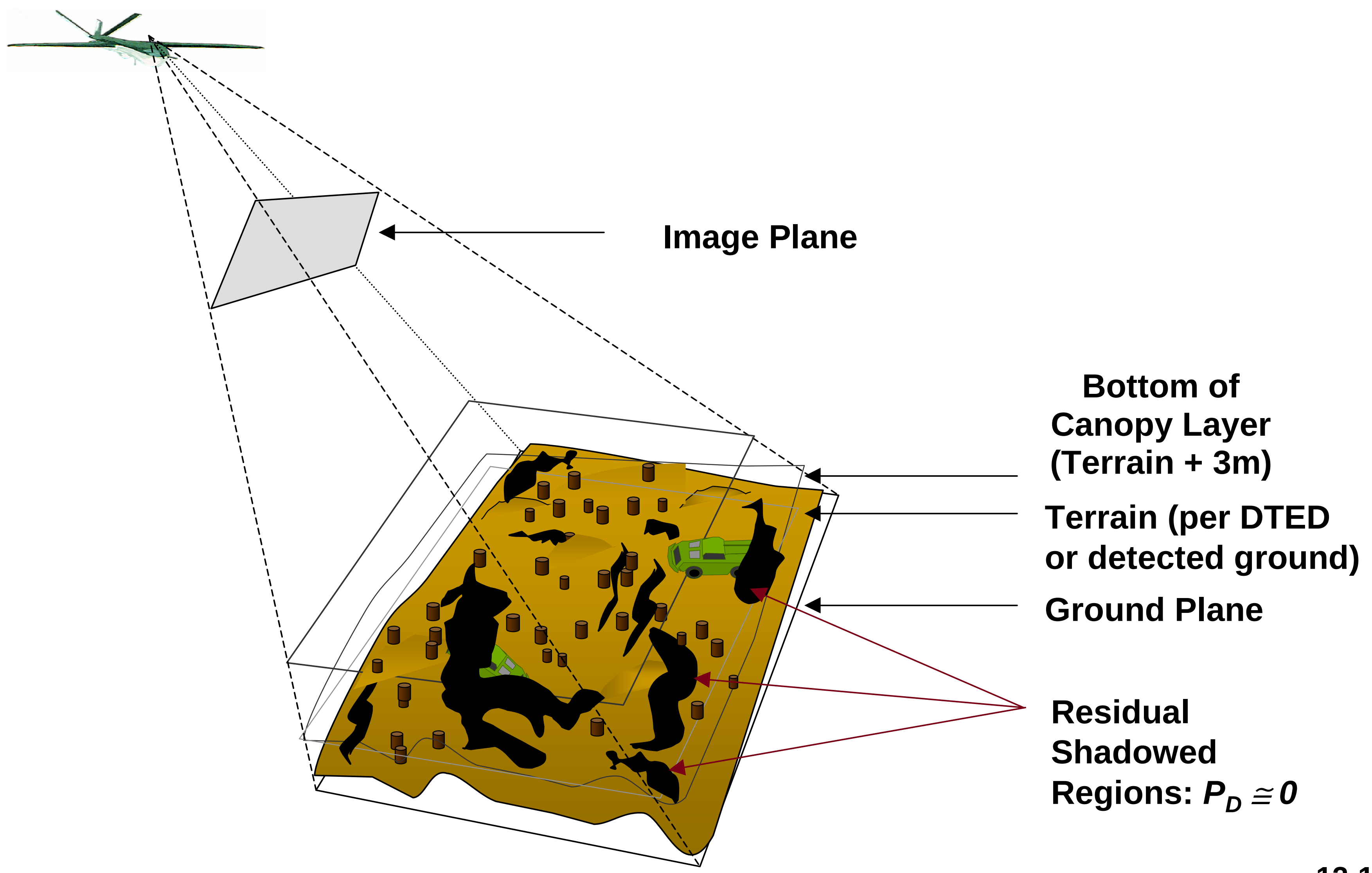
3D Images of Cluttered Environment



Predict Ground



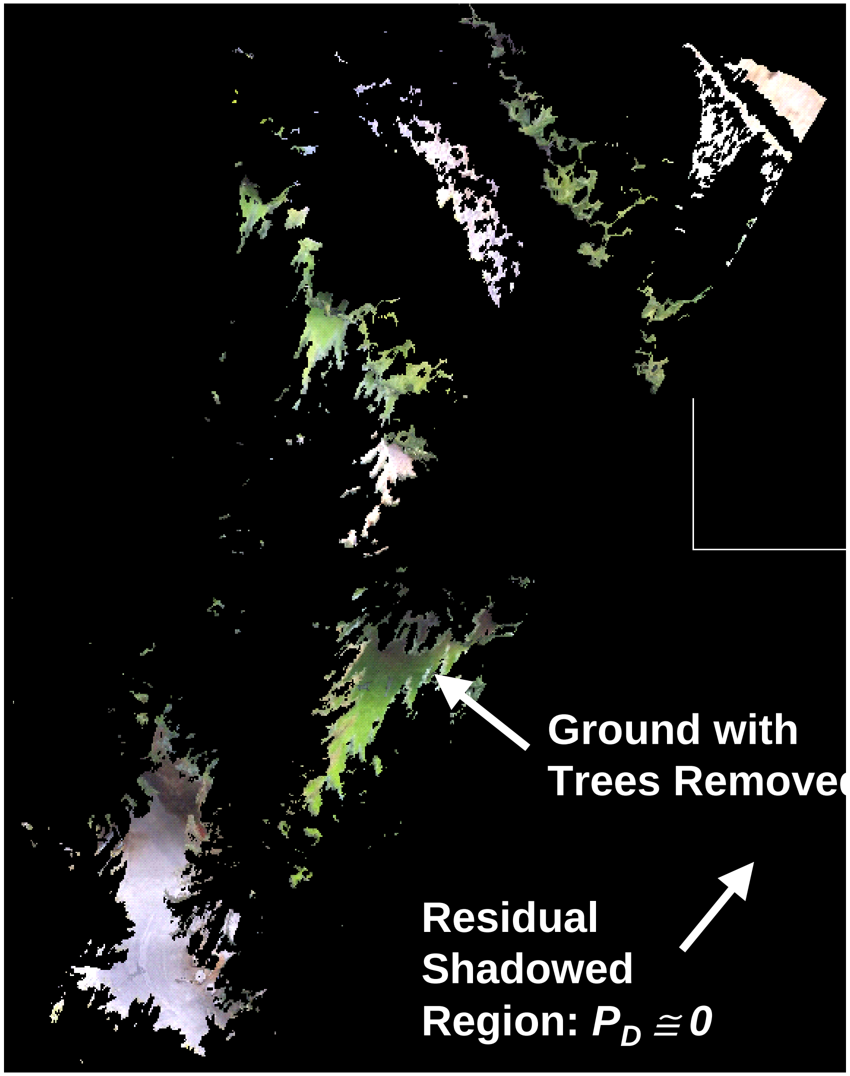
Slice Volume at Bottom of Canopy



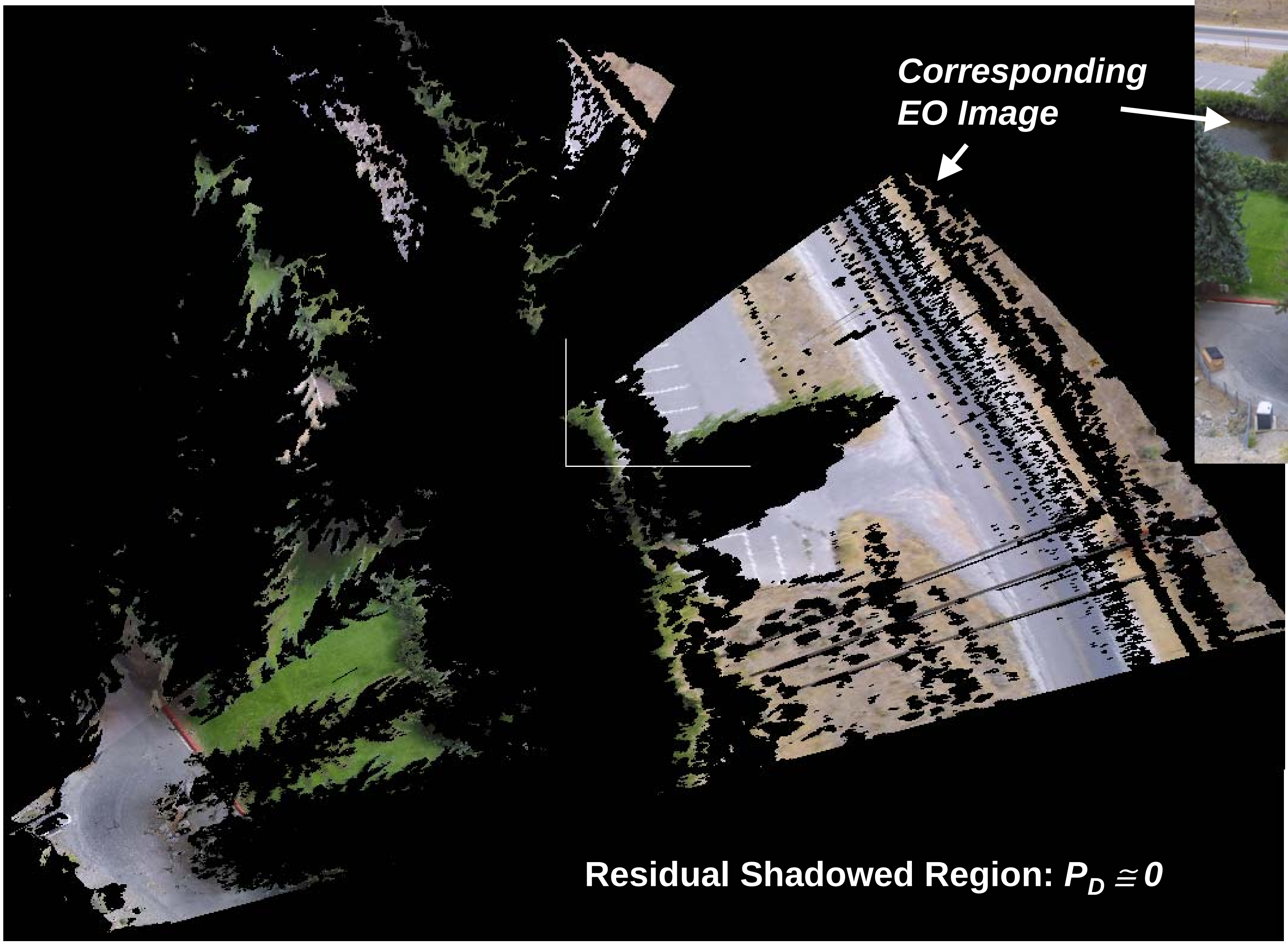
Example of Canopy Slicing

Oblique EO Scene

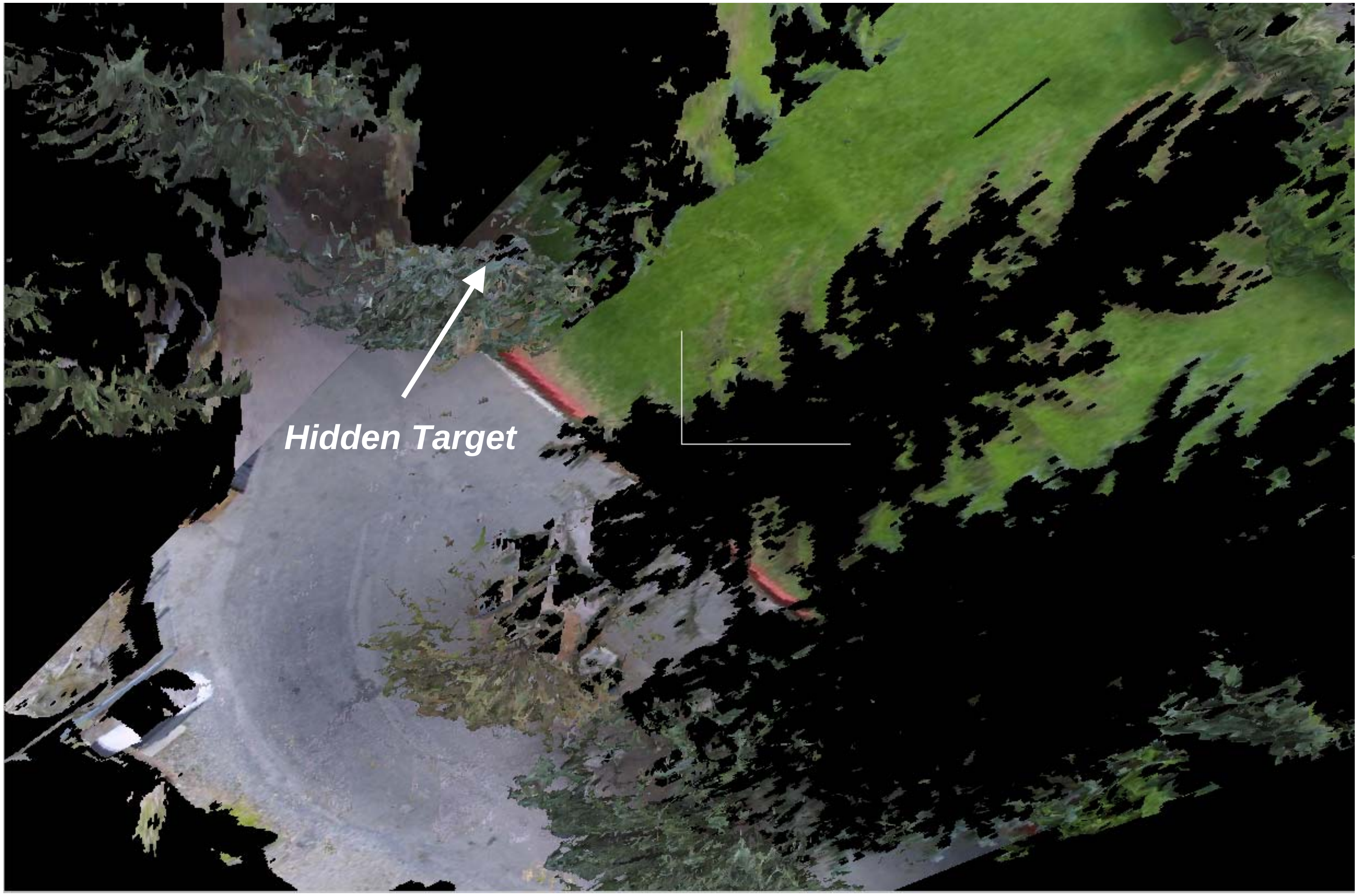
Orthoprojected Using LADAR – Trees Removed



Two Shots Combined – Trees Removed



Target Hidden Under Tree



Target Exposed After Tree Removal

Conclusions (1):
Pixel-Level Fusion of Active/Passive Data for Real-Time Composite Feature Extraction & Visualization

- Pixel-Level fusion of LADAR + EO data facilitates target detection & recognition in highly occluded environments
- Clutter
  - tree canopies, clouds, etc. –

can be removed through geometric filters

Visualization Implication

Some Visualization Implications

- **Target Detection & Recognition**
  - > Probabilities of Detection
  - > Probabilities of Target Presence (prior & posterior)
  - > Exploitation of Negative Data
- **Temporal Evolution of Estimation and Expectations**
  - > Out-of Sequence Data
  - > Situation Projection
  - > Expected Updates

Prior & Posterior Detection Probabilities; e.g. Presentation of Negative Data

Target Detectability Map

$p_D(x,t+n|t,A)$

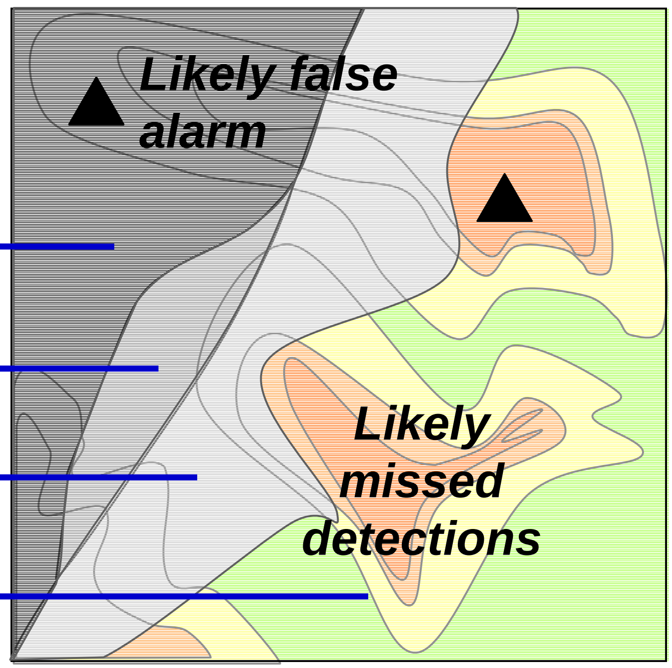
0 - 0.25

0.25 – 0.50

0.50 – 0.75

0.75 - 1.00

Expectations Map



$p(x,t+n|t)p_D(x,t+n|t,A)$

Prior or Posterior Probability Density
(e.g. Track Projection Uncertainty)

$p(x,t+n|t)$

x = Target state (type & location, etc.)

t, $t+n$ = Update times

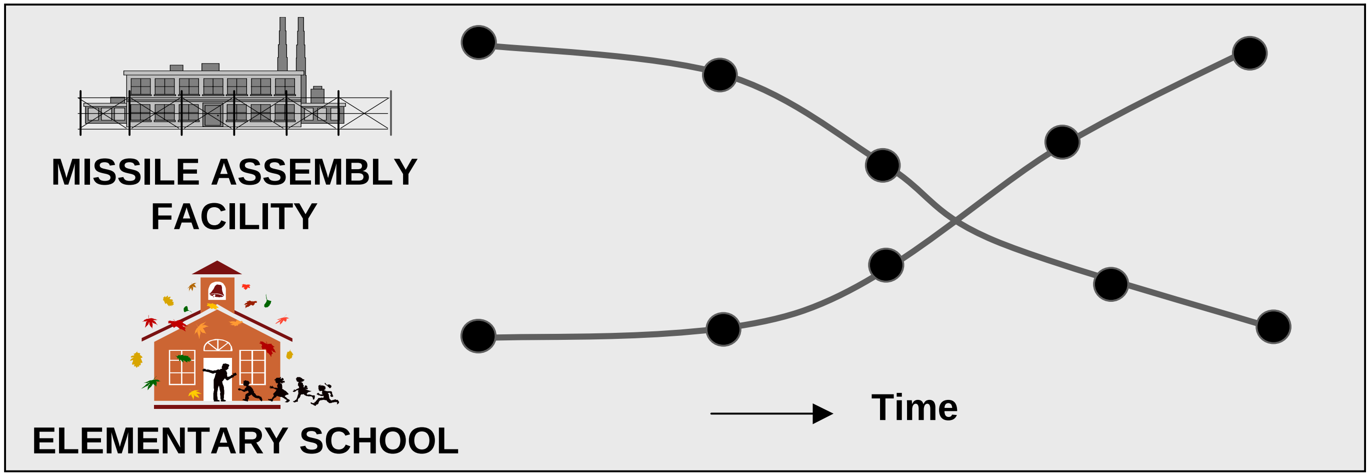
A = Action plan (sensor route, sensor controls, processing controls, etc.)

Some Visualization Implications

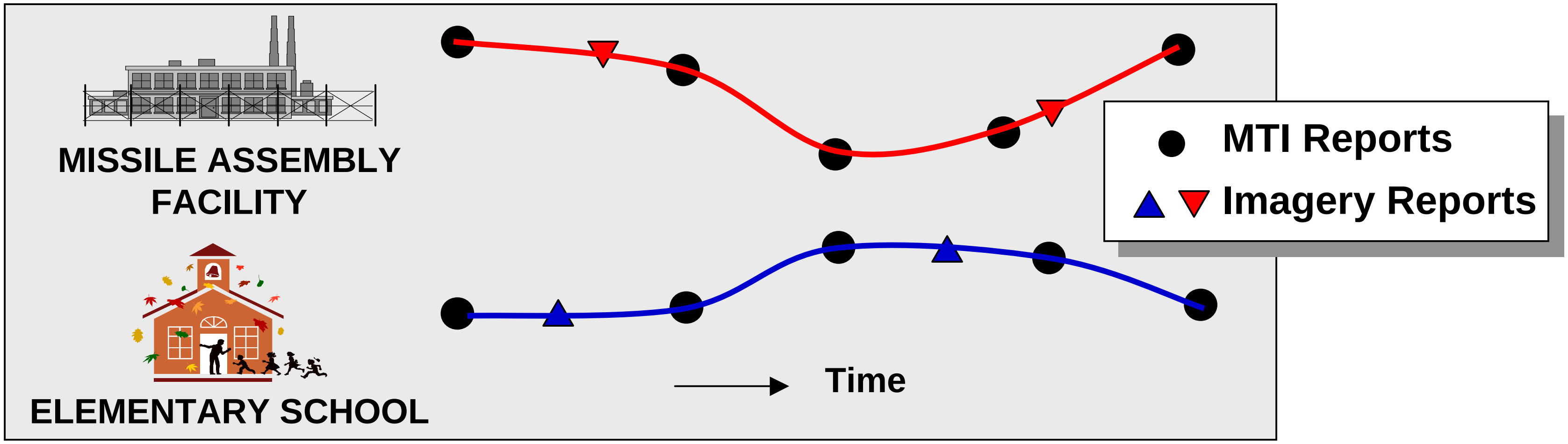
- **Target Detection & Recognition**
  - > Probabilities of Detection
  - > Probabilities of Target Presence (prior & posterior)
  - > Exploitation of Negative Data
- **Temporal Evolution of Estimation and Expectations**
  - > Out-of Sequence Data
  - > Situation Projection
  - > Expected Updates

Latency Issues: Out of Sequence Data

Initial Estimates of Track Histories (MTI only)



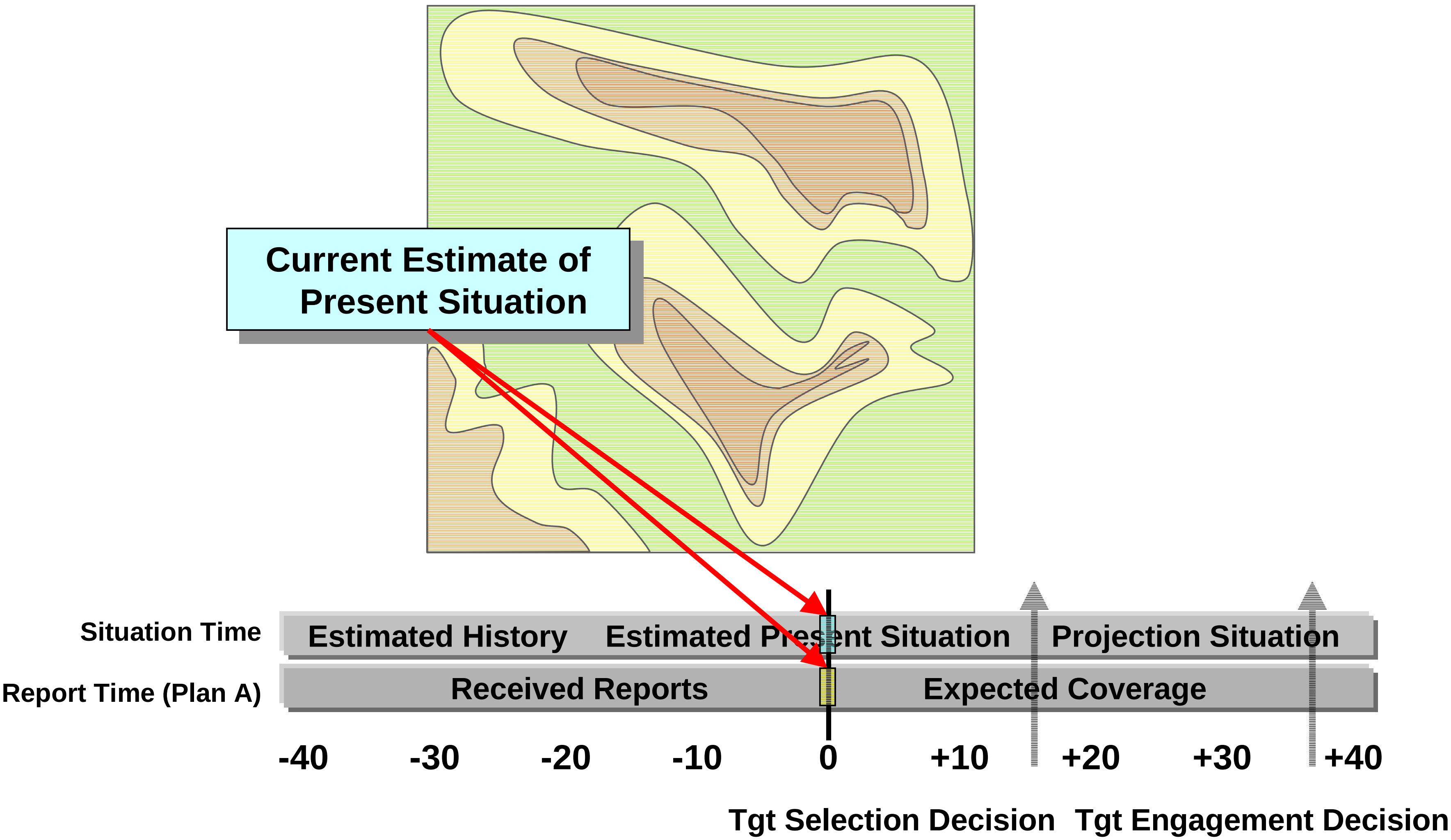
Revised Estimates of Track Histories (MTI + Imagery)



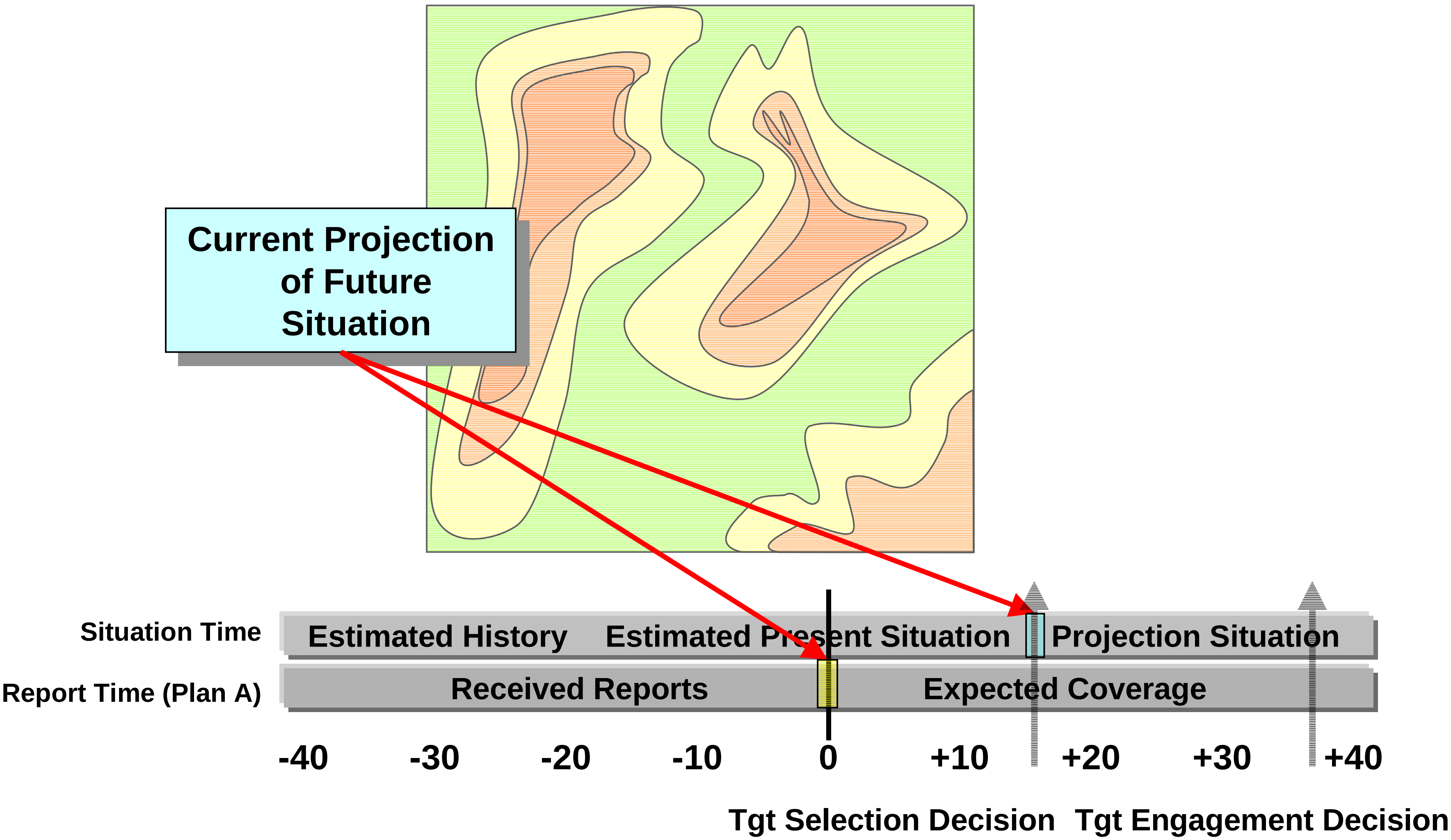
Adaptive Information Exploitation Process

- **Acknowledge uncertainties**
- **Estimate length of time for which decision can be deferred**
- **Estimate probability of resolving ambiguity in time**
    - > Given current collection plan
    - > By redirecting current resources
    - > By adding resource
- **Estimate Cost & Net Utility of Candidate Action Plans**
- **Select & Implement Revised Plan**

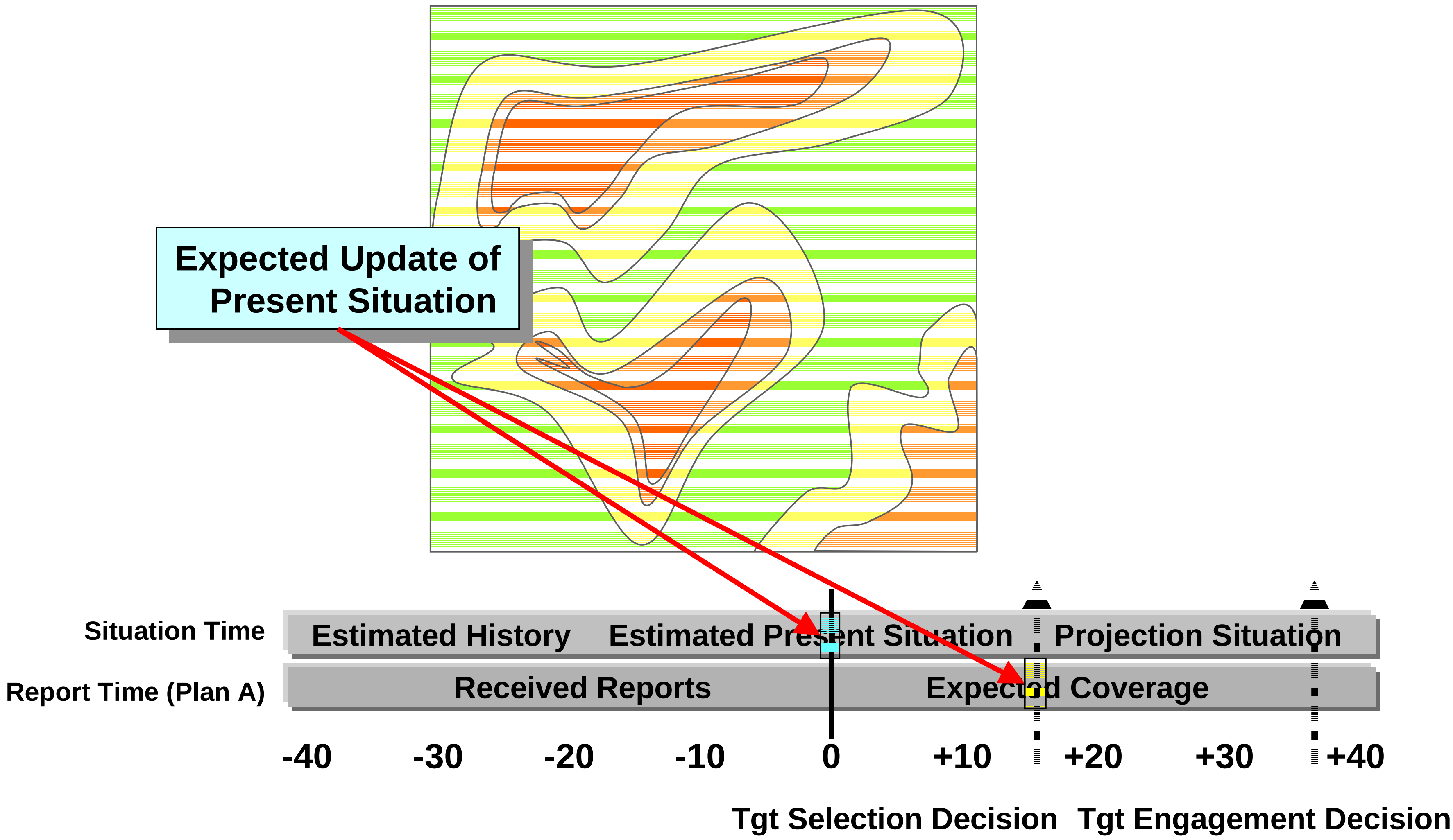
Visualizing Time-Varying Situation Estimation & Expectation (1 of 3)



Visualizing Time-Varying Situation Estimation & Expectation (2 of 3)



Visualizing Time-Varying Situation Estimation & Expectation (3 of 3)



Conclusions

- **Pixel-Level fusion of LADAR + EO data facilitates target detection & recognition in highly occluded environments**
  - > Clutter – tree canopies, clouds, etc. – can be removed over time through geometric filters
- **Enables visualization of time-varying situation estimation & expectation**
  - > Presentation of Detection Probabilities (prior & posterior): e.g. Presenting Negative Data
  - > Presentation of Temporal Evolution of Estimates and of Expectations
    - **Out-of Sequence Data**
    - **Situation Projection**
    - **Expected Updates & Information Evolution**

Thank You

Mange Takk!