Visual and thermal low-altitude aerial imagery for real-time monitoring

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Outline

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2. Challenges
3. Problem definition
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   (A quick overview)
5. Multispectral mosaicking
   (Main focus of this presentation)
6. Conclusion
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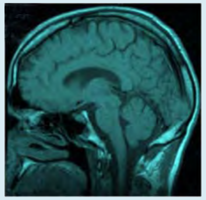
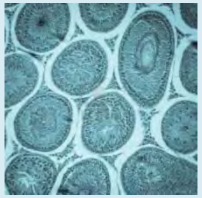
Motivation



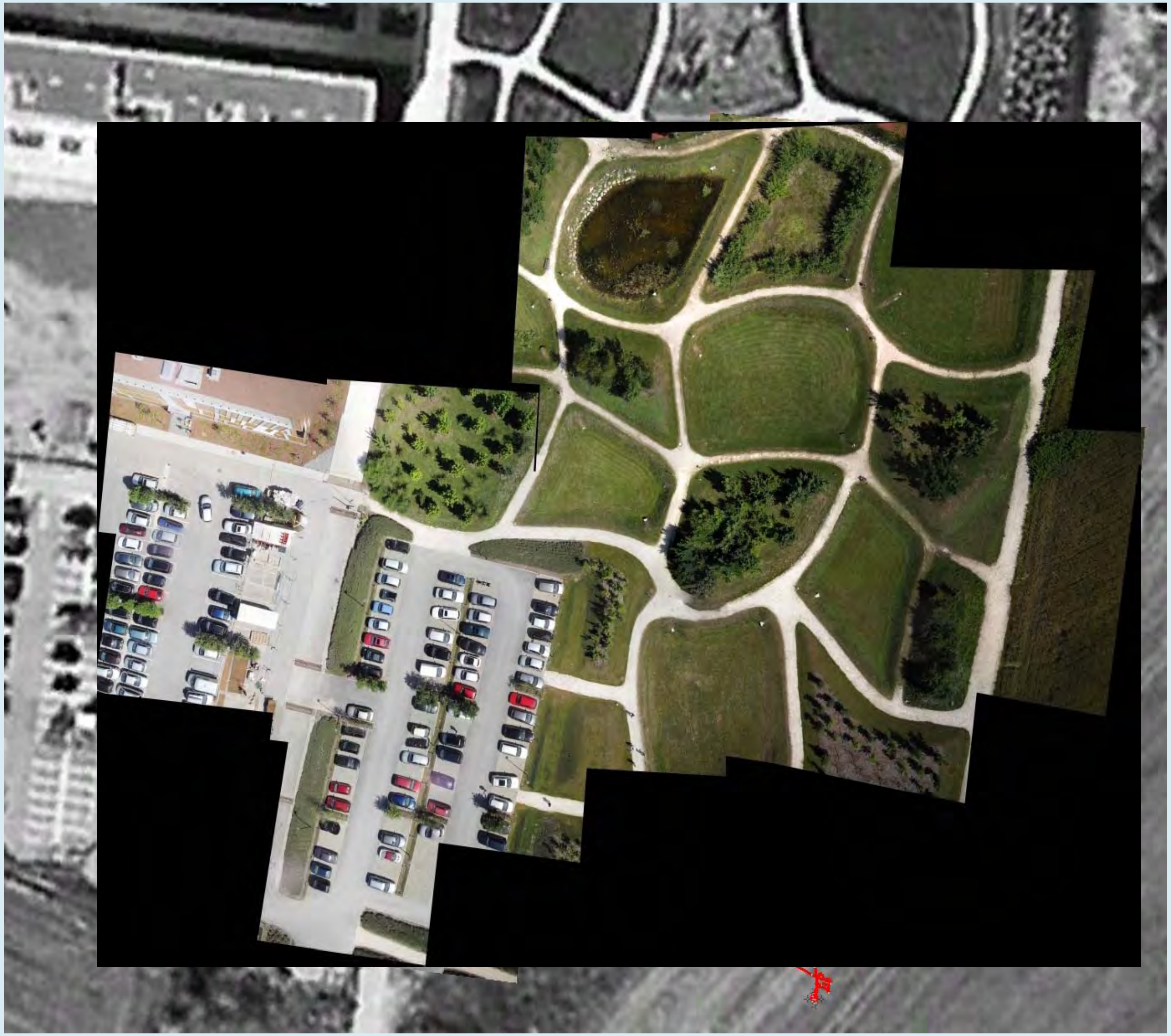
- Advances in computer vision and aerial imagery.

- Small-scale UAVs - easy to deploy.

- Provide overview images similar to Google Maps and Bing Maps, but with higher temporal and spatial resolution.

- Applications of aerial images: environmental monitoring, surveillance, border control, detection, and disaster management.

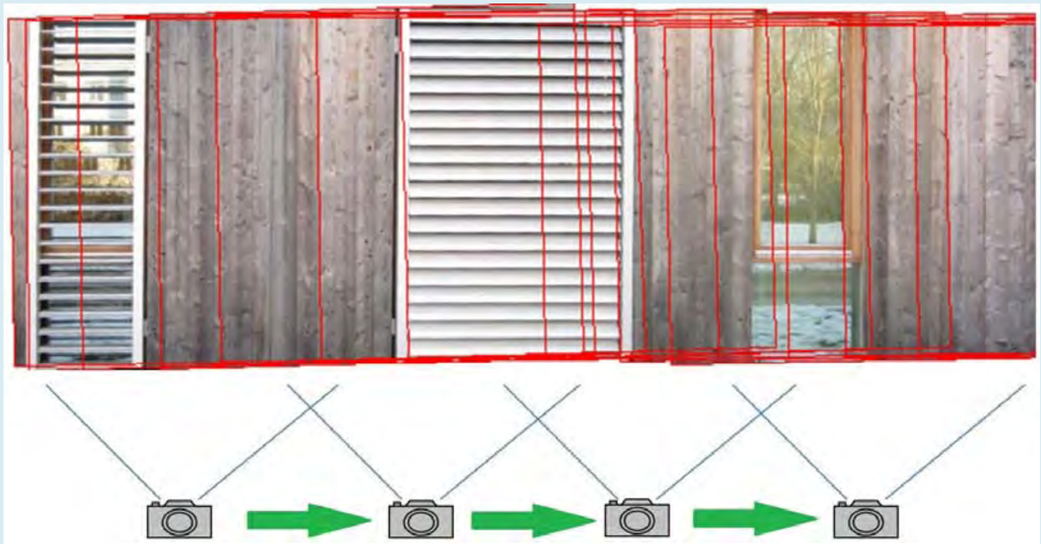
Goal: Generate overview image



Challenges of aerial image mosaicking

- Non-planar scene and low altitude
- Point of view in image acquisition
- Overlapping ratio

Panorama: extension to FOV



Mosaic: extension to POV

Problem definition: (How to mosaick?)

Geosense.   http://www.geosense.com.my/sample_uav_image/Index.htm

Problem definition
(A quick overview)

1. How to use the metadata (IMU & GPS) for mosaicking?

Contribution: A hybrid approach: find adjacent images + approximate positions and orientation

2. How to produce orthorectified mosaics without using the metadata?

Contribution: Study the sources of error + minimize these accumulated errors (low overlap ⇨ no global optimization)

Problem definition
(main focus of this presentation)

3. How to perform a robust interspectral registration between images taken from heterogeneous sensors (e.g., thermal and visual cameras)?

Contributions:

- General lens distortion correction of thermal cameras
- Introduction of feature descriptors for robustly identifying correspondences between images of different spectrums
- Registration of image mosaics
- Registration based on depth maps

Orthorectified mosaicking of UAV images

Mosaic O_n is constructed incrementally

$$O_i = Merge(O_{i-1}, I_i')$$

where O_0 is a zero matrix &

I_i' is a transformation of original image I_i by:

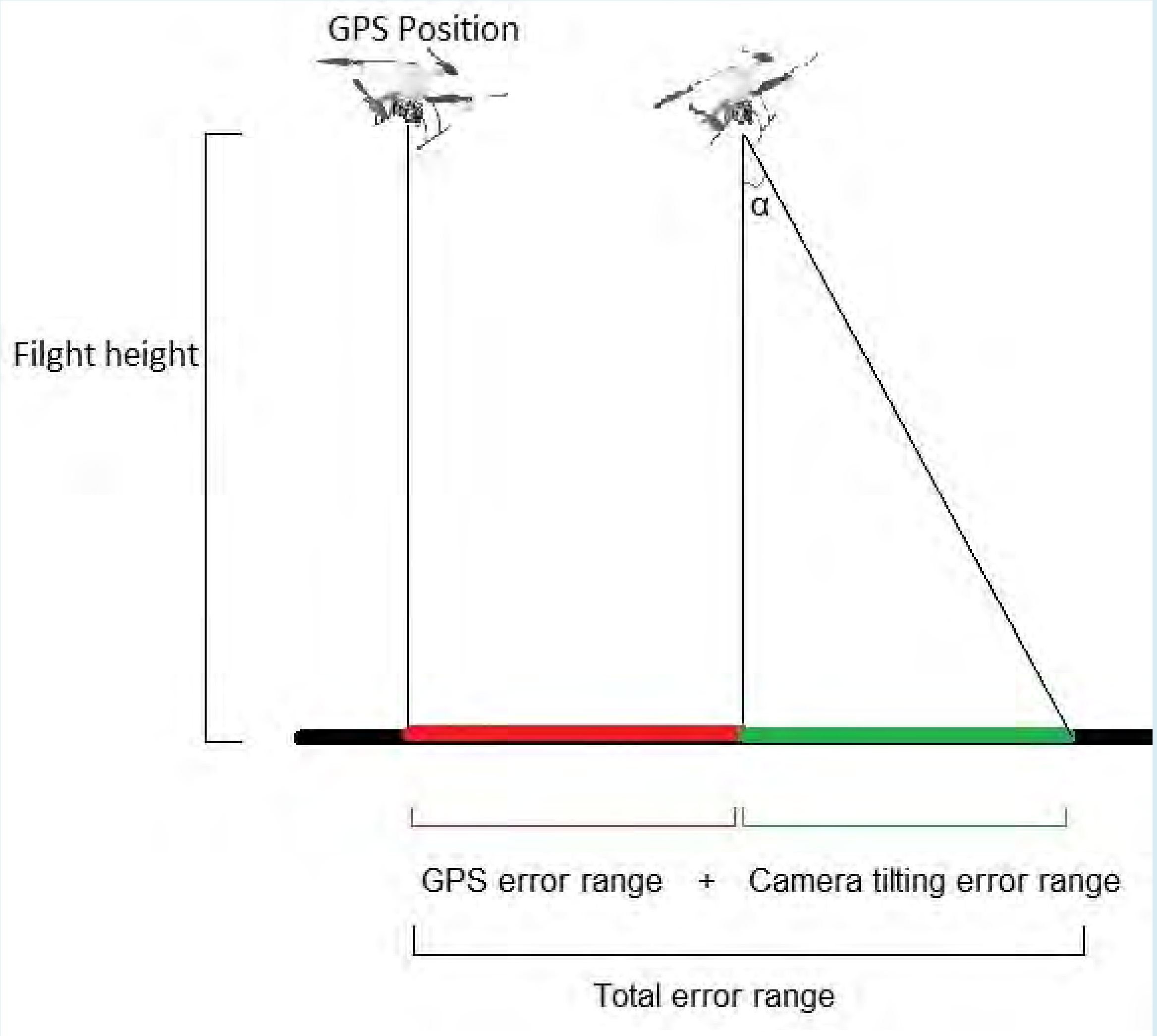
Projective transformation:

$$\tilde{\mathbf{H}}_{I_i,I_i'} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & 1 \end{bmatrix}$$

Orthorectified mosaicking of UAV images

Incremental mosaicking:

1) Hybrid method



Reduce the search space:

1. Place the images based on camera pose
2. Use image-processing to fine tune

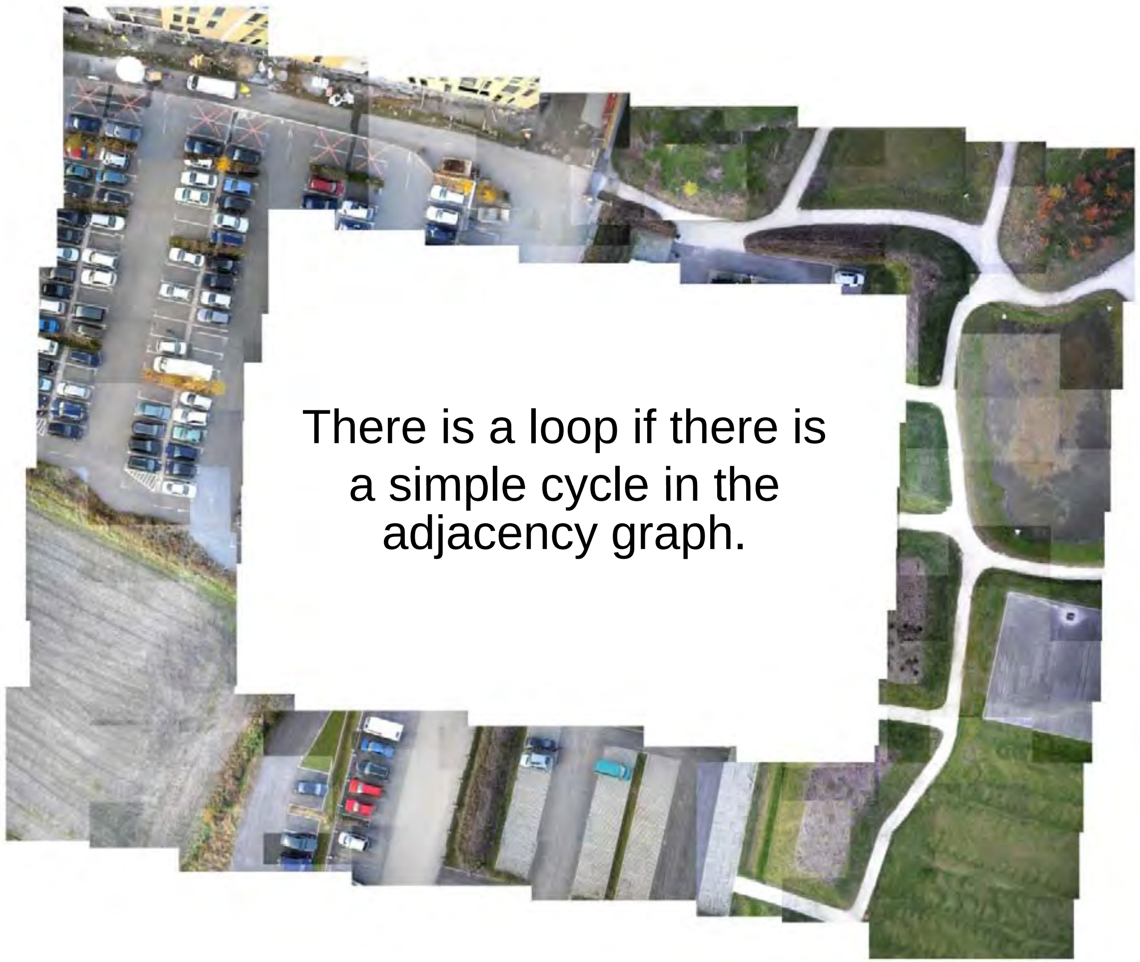
2) Loop-independent mosaicking

Major sources of error in pairwise mosaicking:

1. Unleveled features

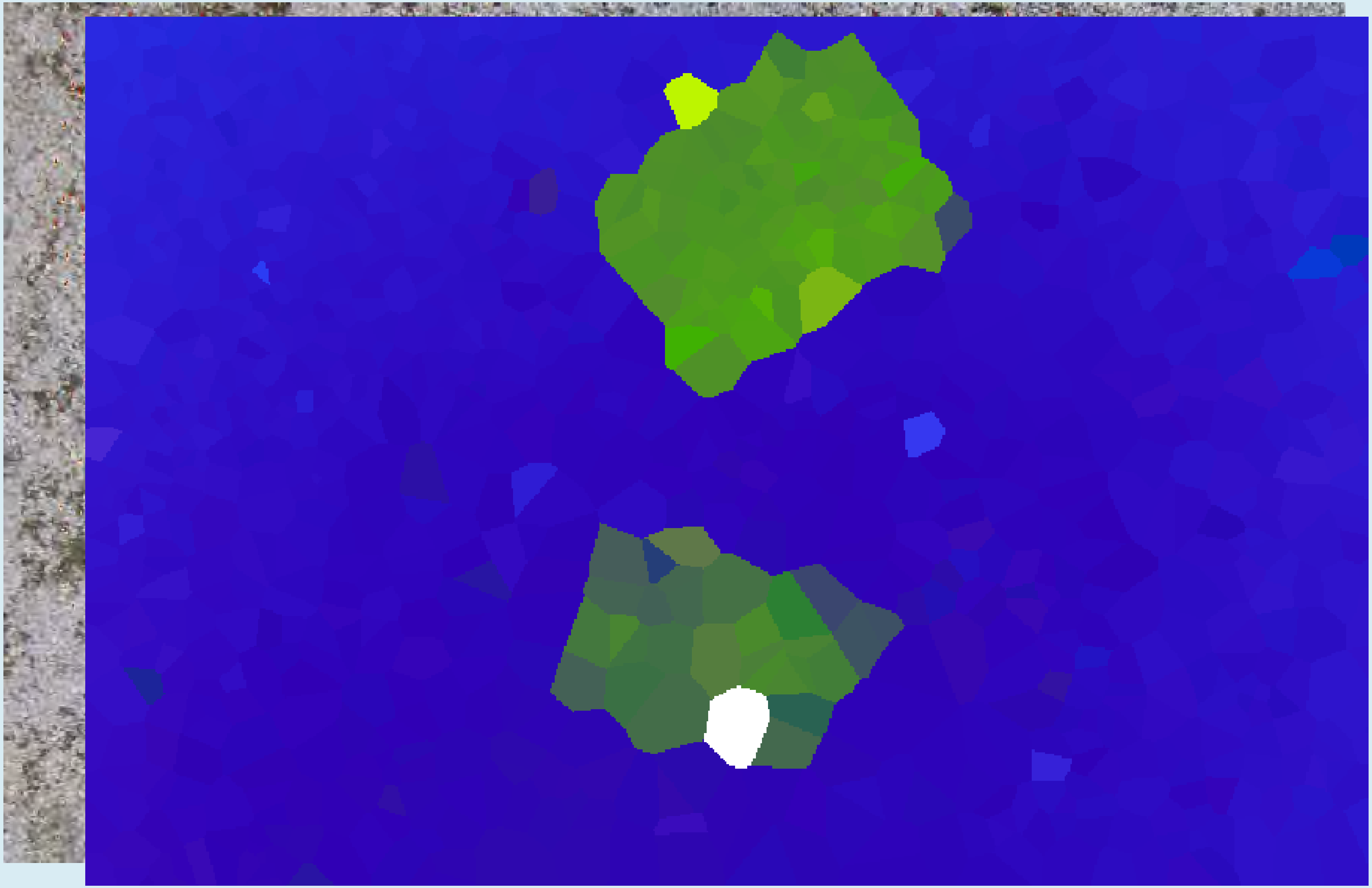
2. Lens distortion

3. Projection and transformation model

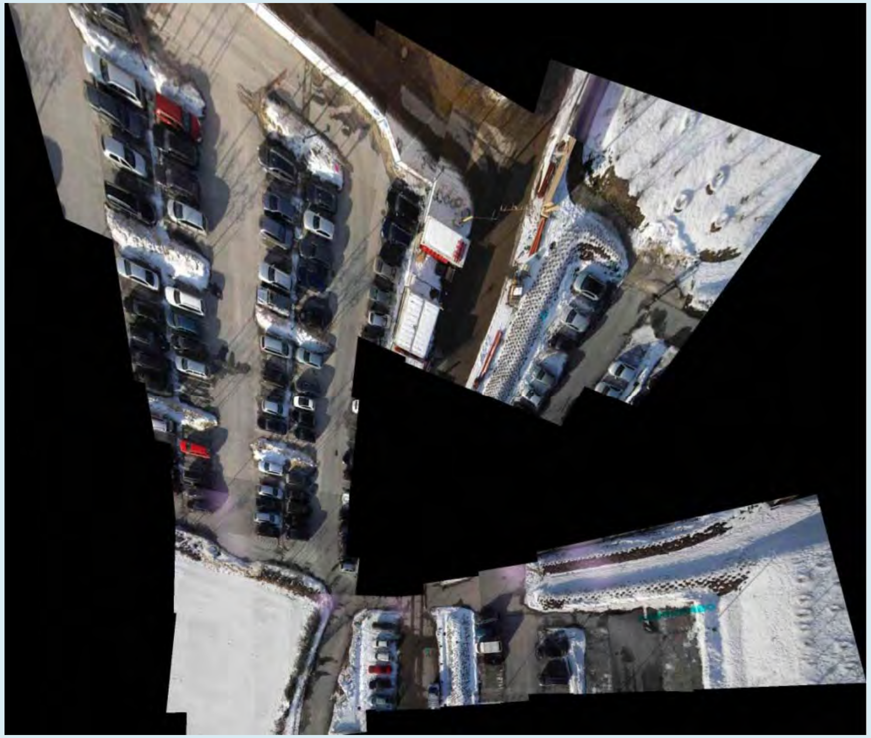


There is a loop if there is a simple cycle in the adjacency graph.

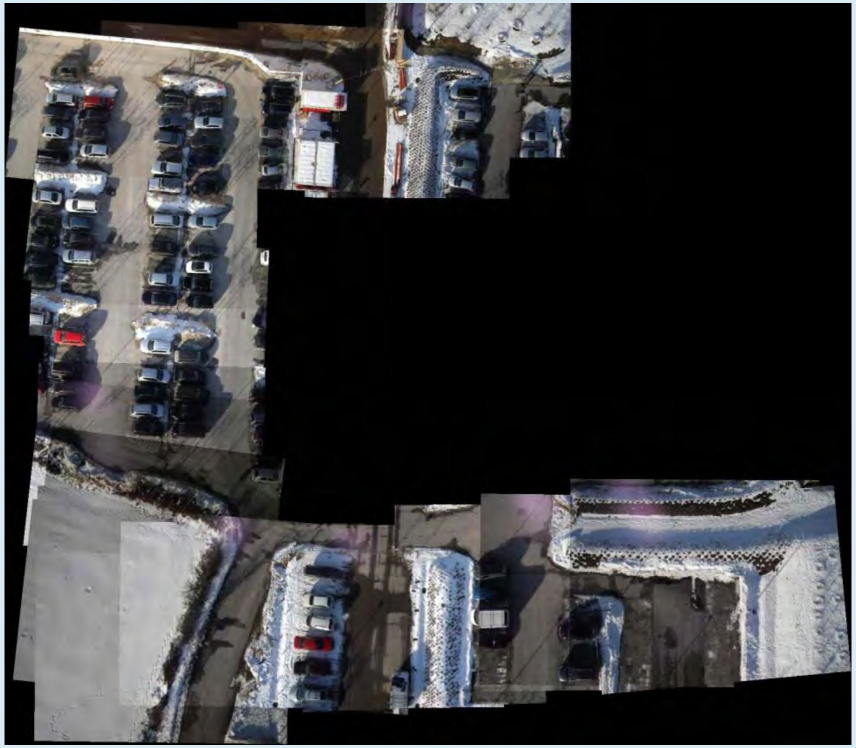
Unleveled features - Disparity implies the depth



Loop-independent mosaicking result



No error control



With considering sources of error

Multispectral aerial imaging

multiple heterogeneous sensors - needs alignment

Visual camera

Thermal camera

Multispectral aerial imaging

General goal: **Register visual and thermal images**

Challenges:

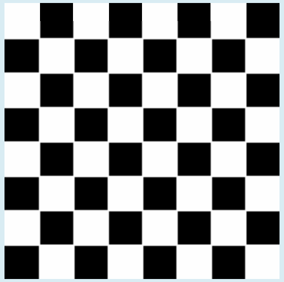
- Different features because of daylight, IR radiation, fog, smoke, water and vegetation

Partial goal: **Correct thermal lens distortion**

Challenges:

- Conventional patterns (e.g. chessboard) is not easily applicable for thermal

Correct thermal lens distortion



conventional chessboard pattern

+

IR radiation,

conveniently generated by a heat lamp

→

Easy to reimplement

&

Accurate

Correct thermal lens distortion

Normal image of the pattern:

Result of our assembly:

$$O = \frac{\sum_i I_i \cdot \lambda(I_i)}{\sum_i \lambda(I_i)}$$

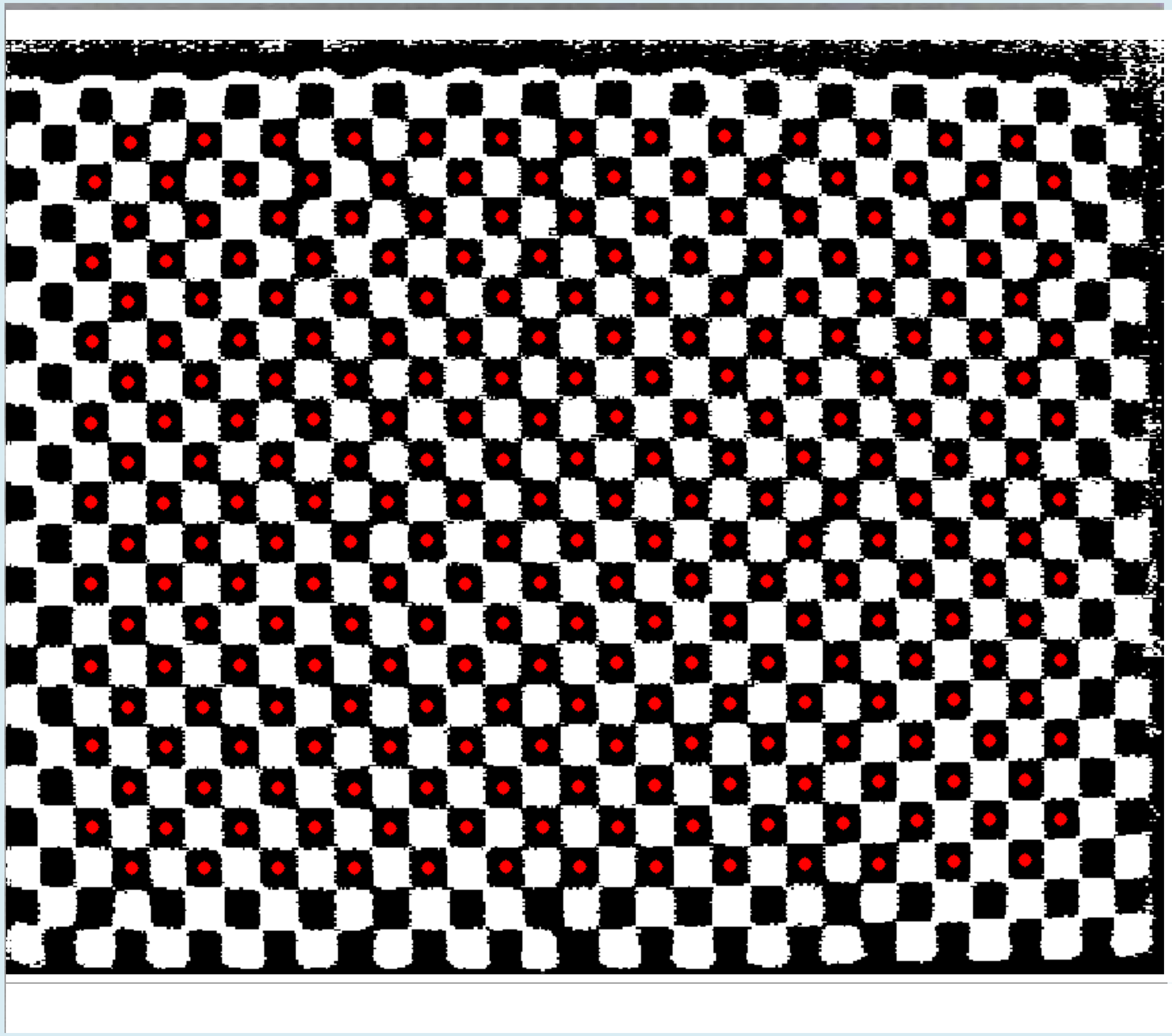
Now it is possible to feed it in existing calibration SW

Adaptive thresholding:

Erosion + Convex hull:

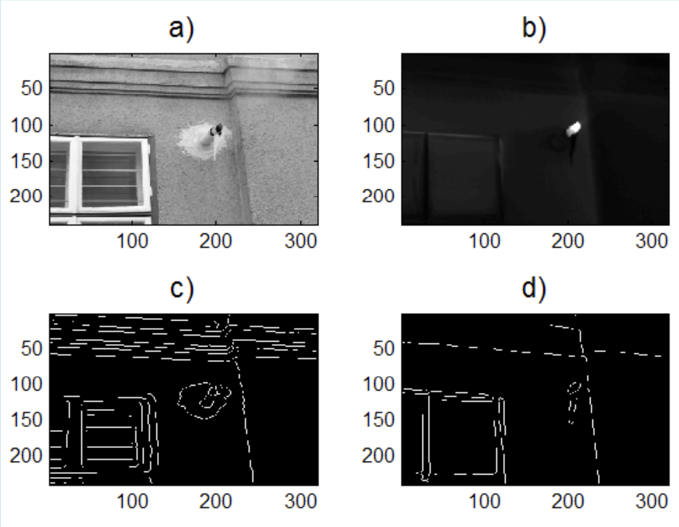
Dilation + Convex hull:

Centers of blobs:

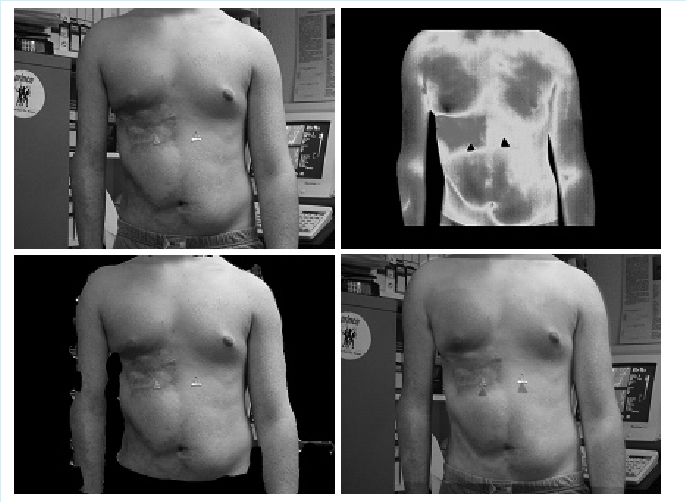


Interspectral registration - State of the art

Interspectral registration (e.g., finding correspondences between thermal and visual images)



➢ R. Istenic, et al.
Thermal and visual image registration in Hough parameter space.
14th International Workshop on Systems, Signals and Image Processing (IWSSIP), pages 106-109, 2007.



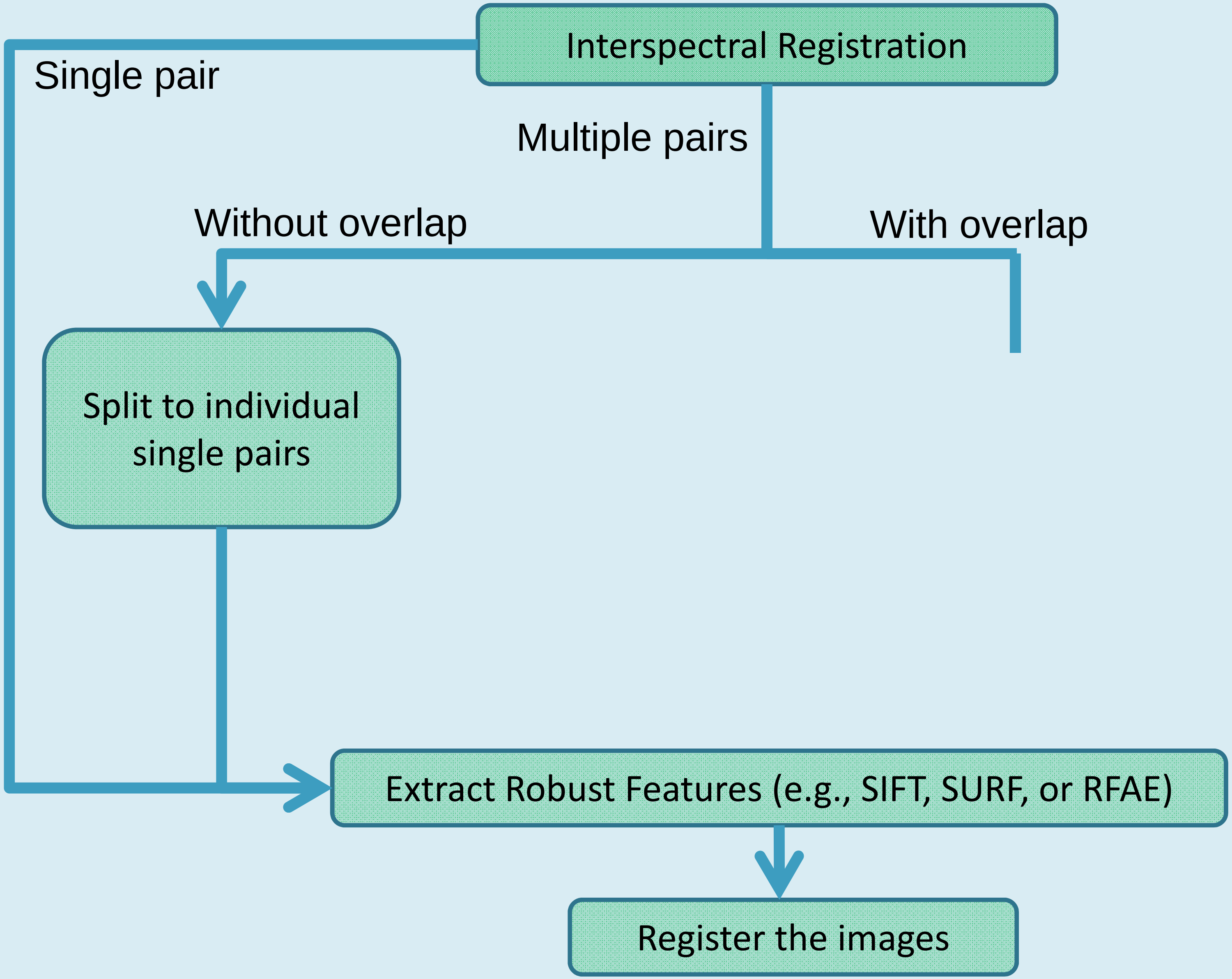
➢ G. Schaefer et al.
User Centered Design for Medical Visualization, chapter Automated overlay of infrared and visual medical images,
pages 174-183. IGI Global, 2008.

State of the art

➢ E. Corias, J. Santamaria, and C. Miravet.
A Segment-based Registration Technique for Visual-IR Images.
Optical Engineering, (1):1-29, 2000.

➢ J. W. Joo, J. W. Choi, and D. L. Cho.
Robust registration in two heterogeneous sequence images on moving objects.
In Proceedings of Sixth International Conference of Information Fusion, pages 277-282, 2003.

Interspectral registration pipeline



Interspectral registration – single pair

- Scale-, rotation-, and illumination-invariant
- Manipulate existing descriptors (e.g., SIFT or SURF)
- Robust Features Along the Edges (RFAE)

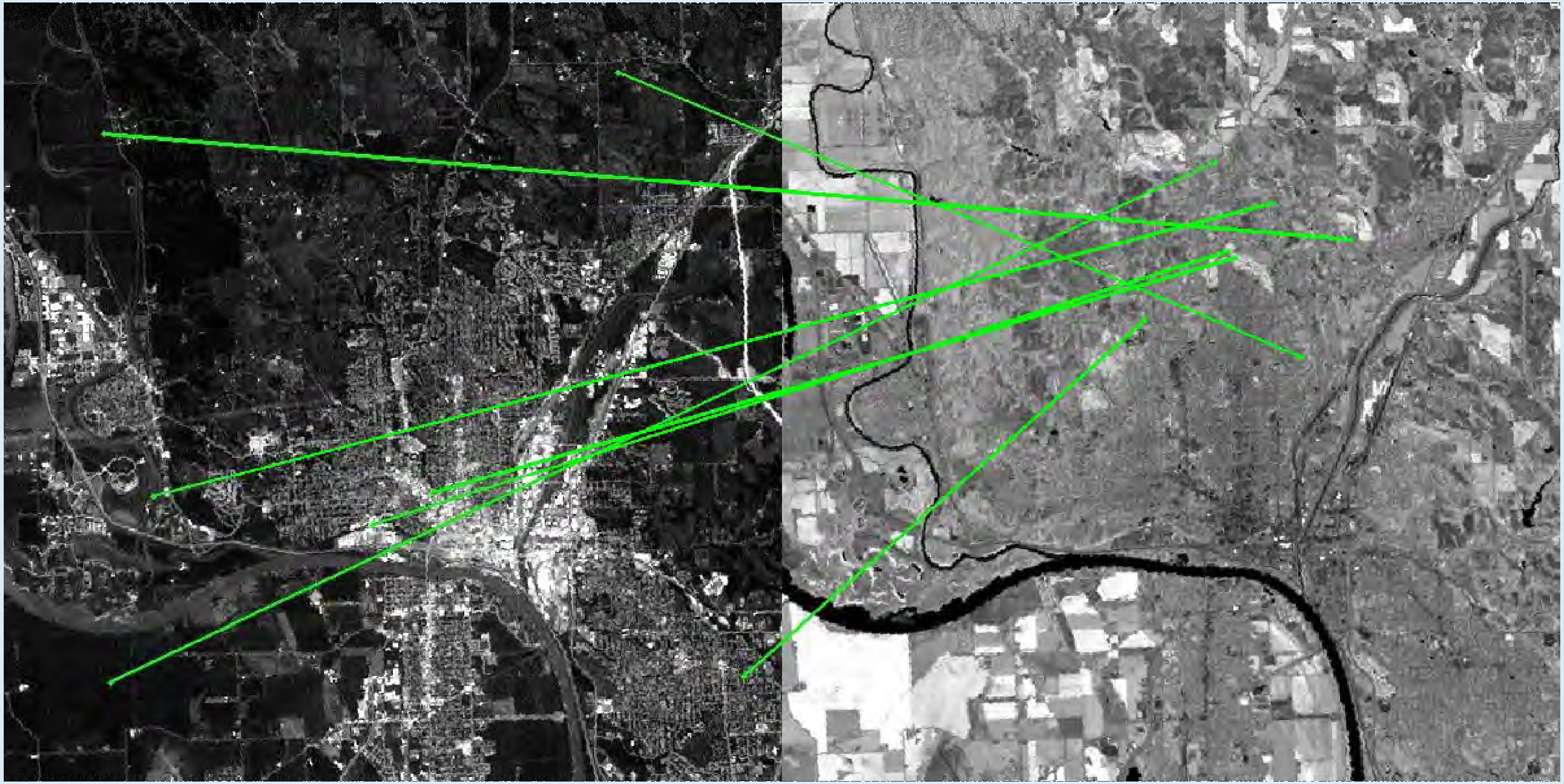
$$D_E(x,y,\sigma) = (G(x,y,k\sigma) - G(x,y,\sigma)) * B \circ S(I(x,y),\theta),$$

where B is the binary operator and S is the Sobel operator

79 SURF
89 RFAE
features

Successful
Failed
Registration

Single pair registration – Satellite sample

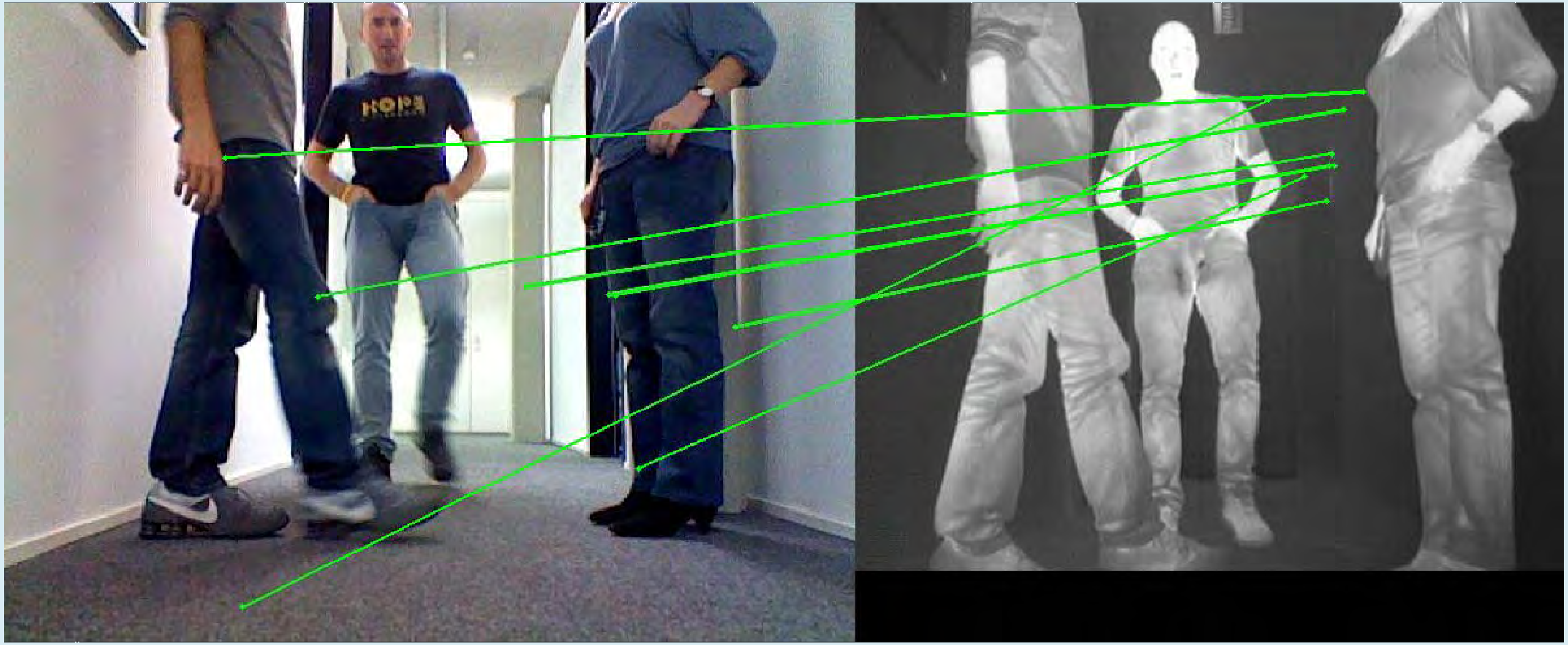


Bands 1 and 4 of the Landsat satellite image of Iowa state (image source: NASA/USGS).

Single pair registration – Human sample

RIS Successful Registration

SURF Failed Registration



Visual and thermal images of humans

Interspectral registration evaluation – single pair

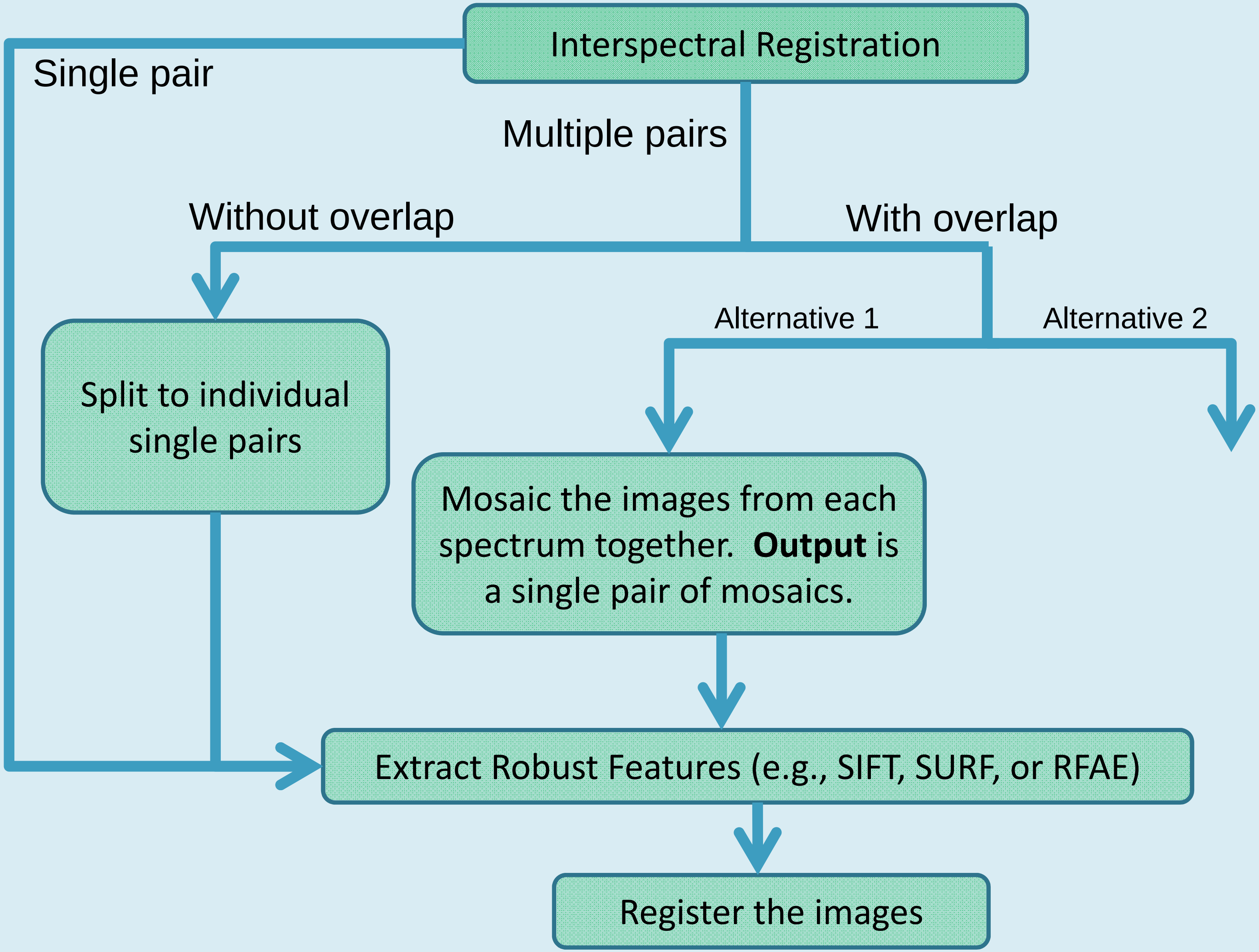
Successful registration ratio

	SIFT	SURF	U-SURF	RFAE	SURF+ RFAE
Satellite (low deviation)	24/24	24/24	24/24	24/24	24/24
Satellite (high deviation)	7/10	6/10	9/10	10/10	10/10
Human	0/16	0/16	2/16	12/16	12/16
Surveillance	1/14	2/14	4/14	12/14	12/14
UAV	13/20	14/20	2/20	13/20	17/20

Average quality (Q values are calculated based on coverage and sparsity of features)

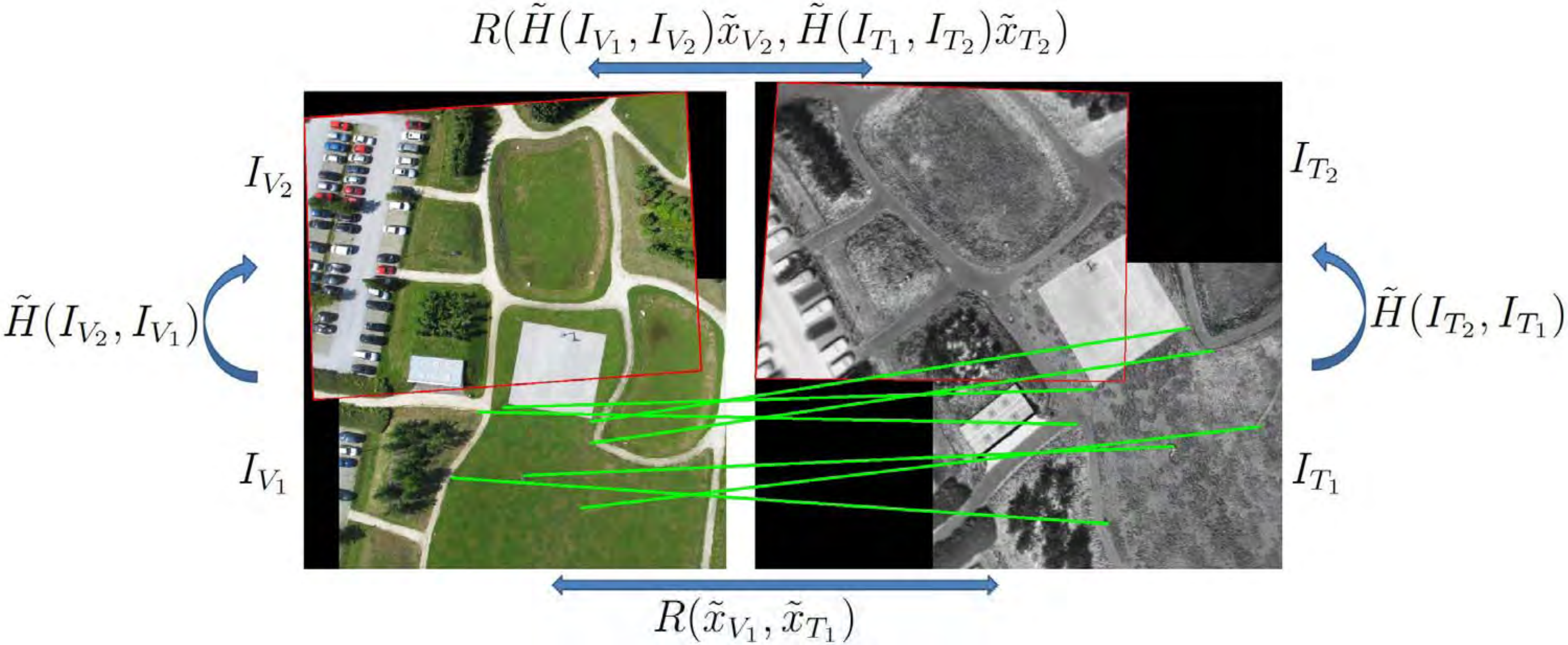
	SIFT	SURF	U-SURF	RFAE	SURF+ RFAE
Satellite (low deviation)	72 %	66 %	71 %	53 %	68 %
Satellite (high deviation)	45 %	41 %	49 %	46 %	52 %
Human	0 %	0 %	1 %	8 %	8 %
Surveillance	1 %	3 %	4 %	18 %	19 %
UAV	9 %	10 %	1 %	6 %	11 %

Interspectral registration pipeline



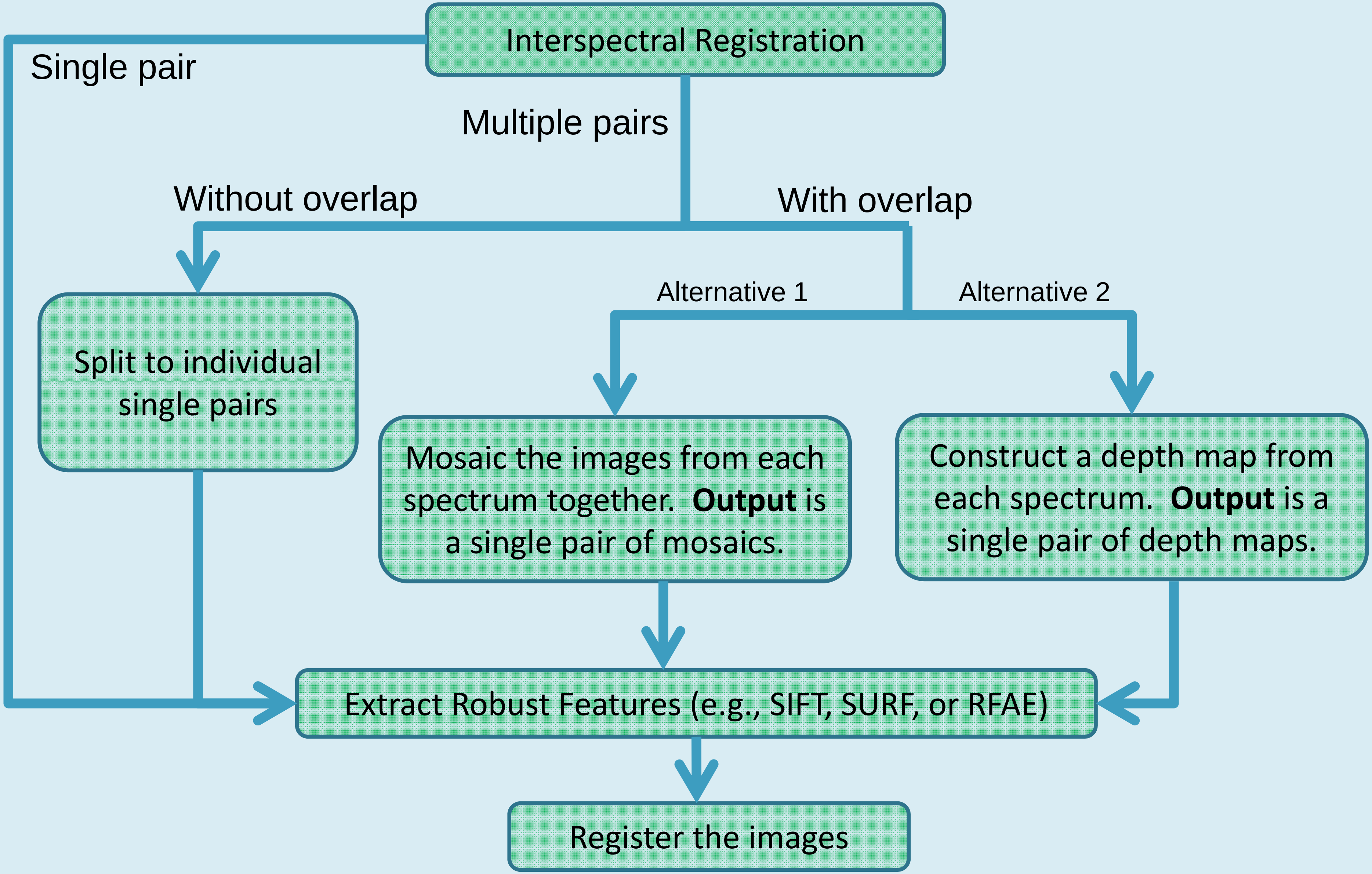
Interspectral registration – multiple pairs

- Register the mosaics if they have enough overlaps



$$R(\tilde{\mathbf{x}}_{V_2}, \tilde{\mathbf{x}}_{T_2}) = R(\tilde{\mathbf{H}}_{I_{V_1}, I_{V_2}} \tilde{\mathbf{x}}_{V_2}, \tilde{\mathbf{H}}_{I_{T_1}, I_{T_2}} \tilde{\mathbf{x}}_{T_2})$$

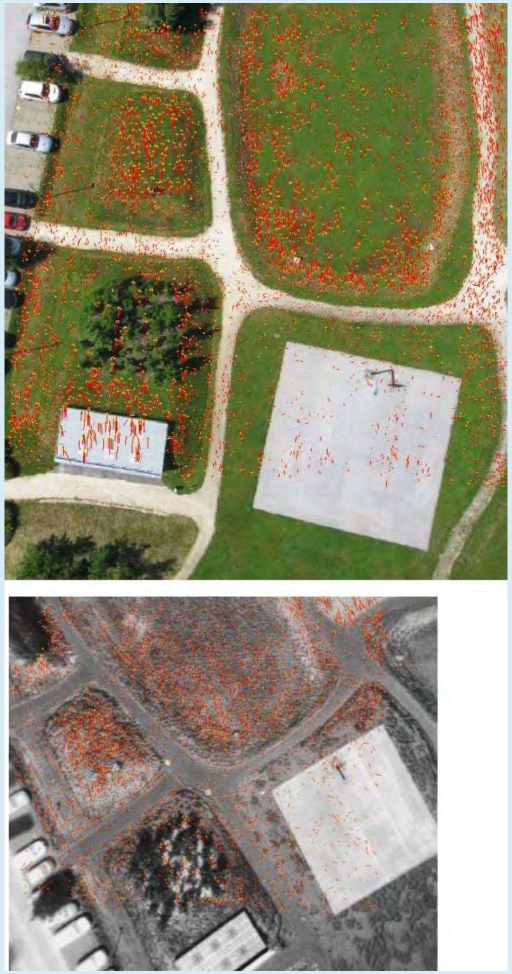
Interspectral registration pipeline



Interspectral registration – multiple pairs

➢ Exploit the 3D structure – rough depth map

+



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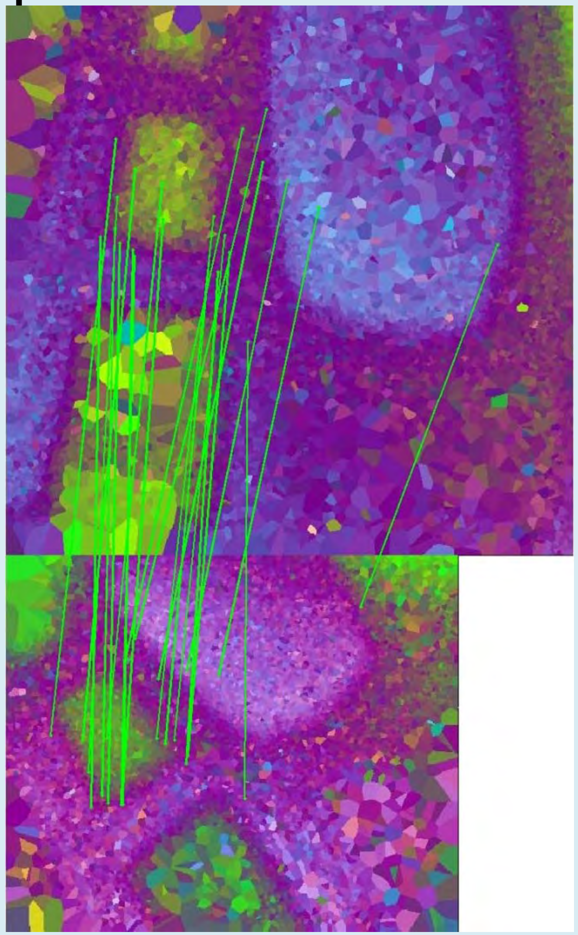
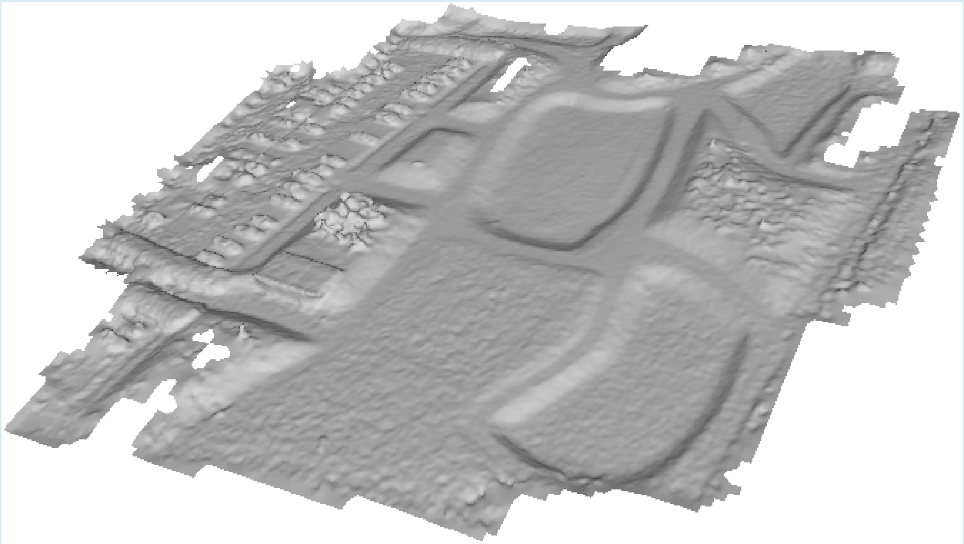


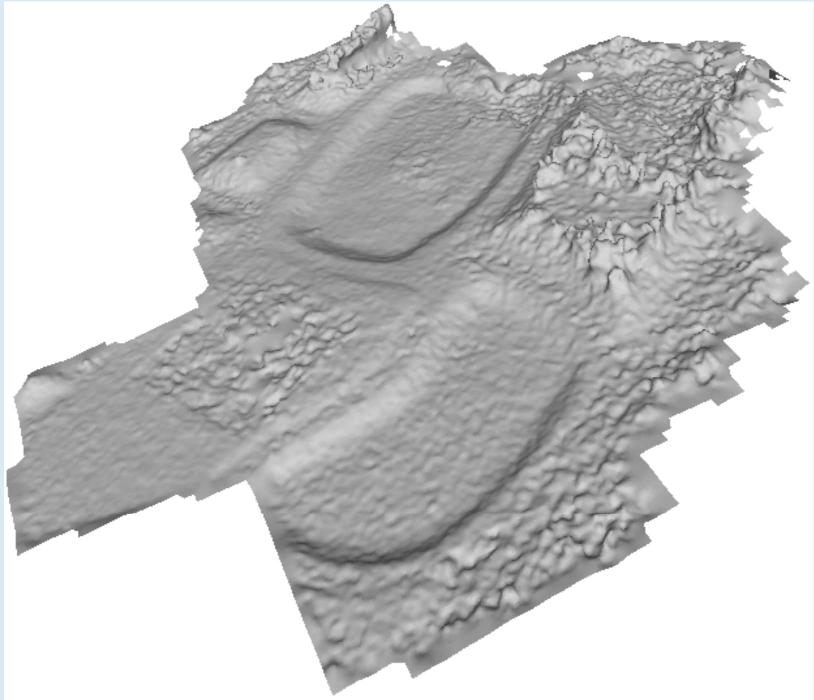
Depth map registration

Interspectral registration – multiple pairs

- Exploit the 3D structure – full reconstruction



3D model from 25 visual images



3D model from 25 thermal images

Interspectral registration – multiple pairs

➢ Project 3D to 2D – equivalent depth map

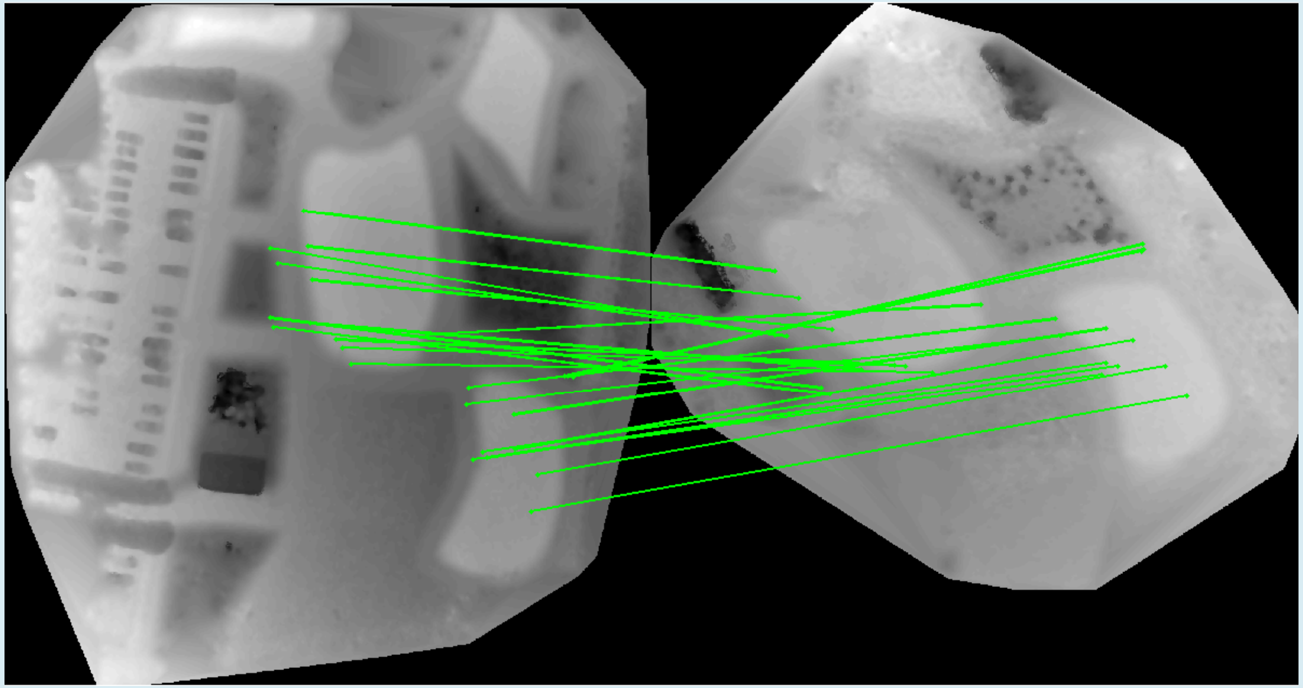
Perpendicular base point on plane

$$\mathbf{P}_\pi = \mathbf{P}_0 - \frac{(ax_0 + by_0 + cz_0 + d)}{a^2 + b^2 + c^2}\mathbf{n}$$

Distance of the point to the plane

$$\mathrm{d}(\mathrm{P}_0, \pi) = |\mathrm{P}_0 - \mathrm{V}_0|\cos\theta = \frac{\mathbf{n}\cdot(\mathrm{P}_0 - \mathrm{V}_0)}{|\mathbf{n}|} = \frac{ax_0 + by_0 + cz_0 + d}{\sqrt{a^2 + b^2 + c^2}}$$

SURF
over
depth map

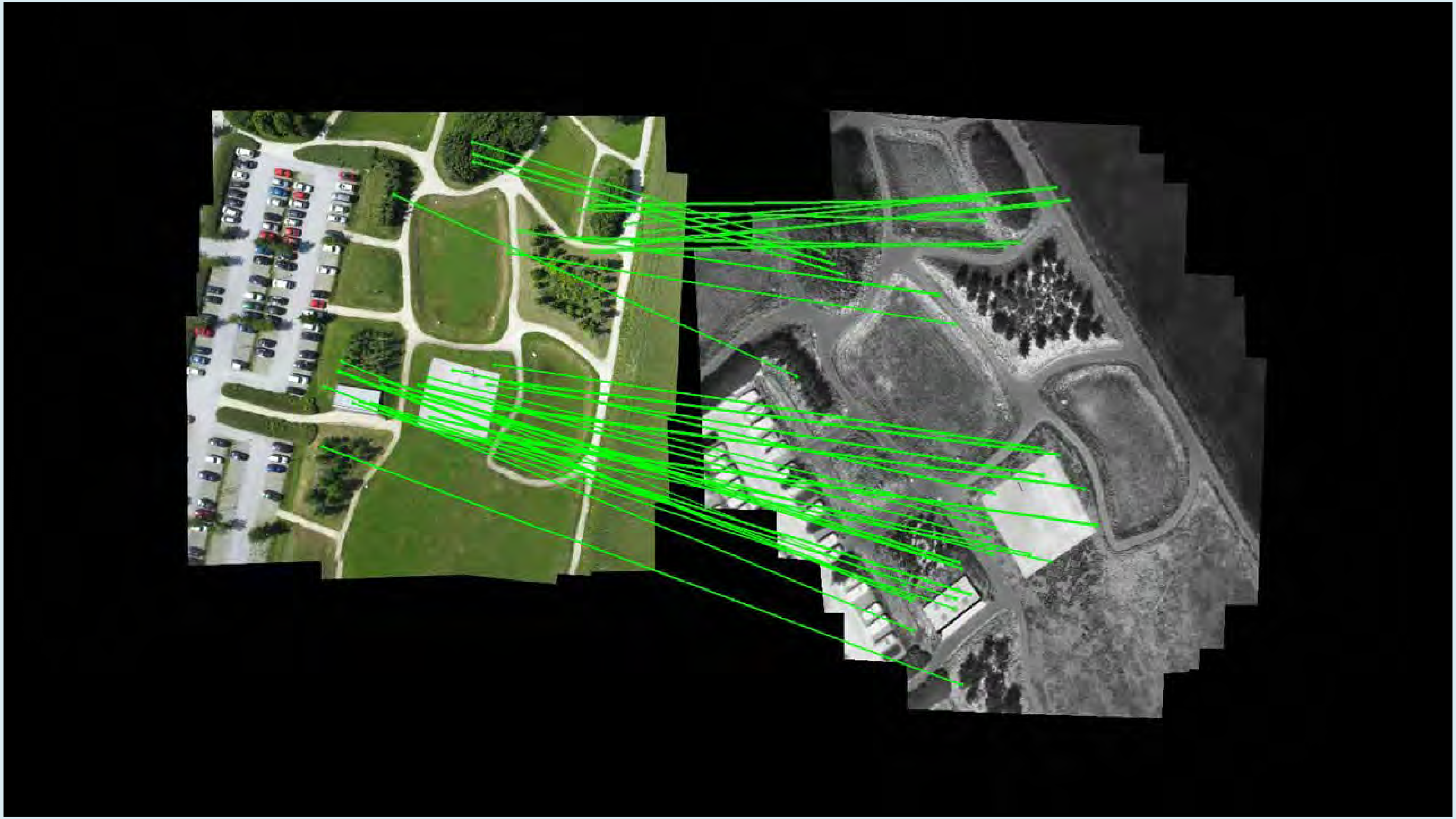


Multiple pair registration - depth map sample

S l registration usin different seasons ors

Surf failed - same sensor but different seasons

Alignment sample – Multispectral image



Conclusion

We construct high-resolution mosaic images with high geometric accuracy from a set of images taken from small-scale UAVs.

- Present a hybrid approach which combines metadata and the image data (increased accuracy and 70% computational time reduction)
- Quantify the influence of different parameters - studying the sources of error in pairwise mosaicking
  (increased accuracy with the same complexity)
- Robust interspectral image registration
  - A general method (RFAE) which exploits the existing scale-invariant feature extraction methods such as SIFT and SURF
  - Register the image mosaics (complexity *n* times more, for *n* images)
  - Use depth maps of a target scene for the feature extraction
    (For a rough depth map 4*n* times more, for *n* images)

Future work

- Advanced UAVs: handle higher resolution or videos

- Hybrid approach: improve optimization (heuristic)

- Loop-independent mosaicking: generalize in presence of loop

- Interspectral registration: more complex features
  (e.g., classified areas or object can be used, SGM)

- System level future works: Underlying architectures for deployment of multi-UAV, autonomous planning and deployment, communication structure, and optimal coverage methods

Questions?

Thank you for your attention!