Registration of Textured Remote Sensing Images Using Directional Gabor Frames

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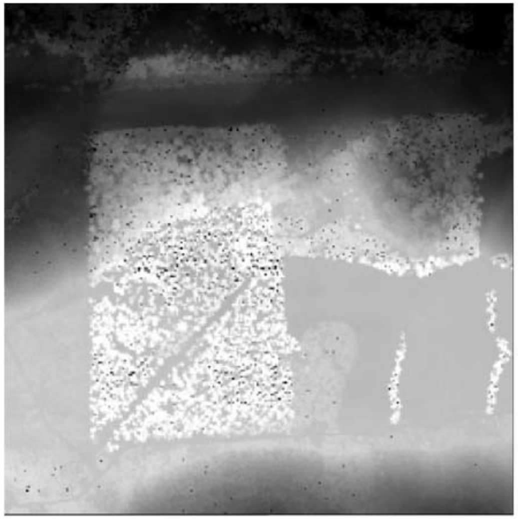
Background on Image Registration

- The process of image registration seeks to align two or more images of approximately the same scene, but taken under different conditions, i.e., acquired at different times or with different sensors.

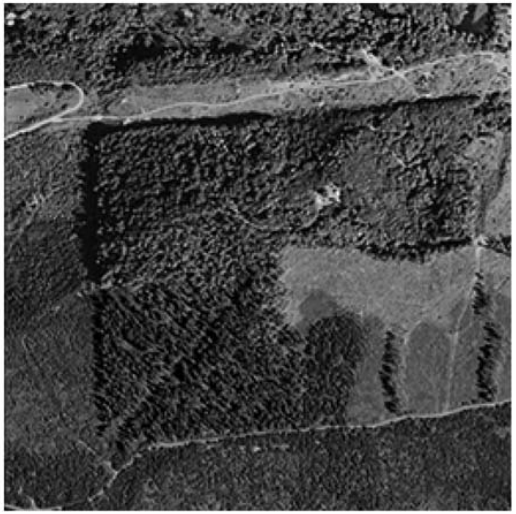
- Image registration may be viewed as the combination of four separate processes:
    1. Selecting an appropriate **search space** of admissible transformations.
    2. Extracting relevant **features** to be used for matching.
    3. Selecting a **similarity metric** in order to decide if a transformed input image closely matches the reference image.
    4. Selecting a **search strategy**, which is used to match the images based on maximizing or minimizing the similarity metric.

Lidar and Multimodal Image Registration

Lidar Airborne Laser Swath Mapping (ALSM) Elevation Image



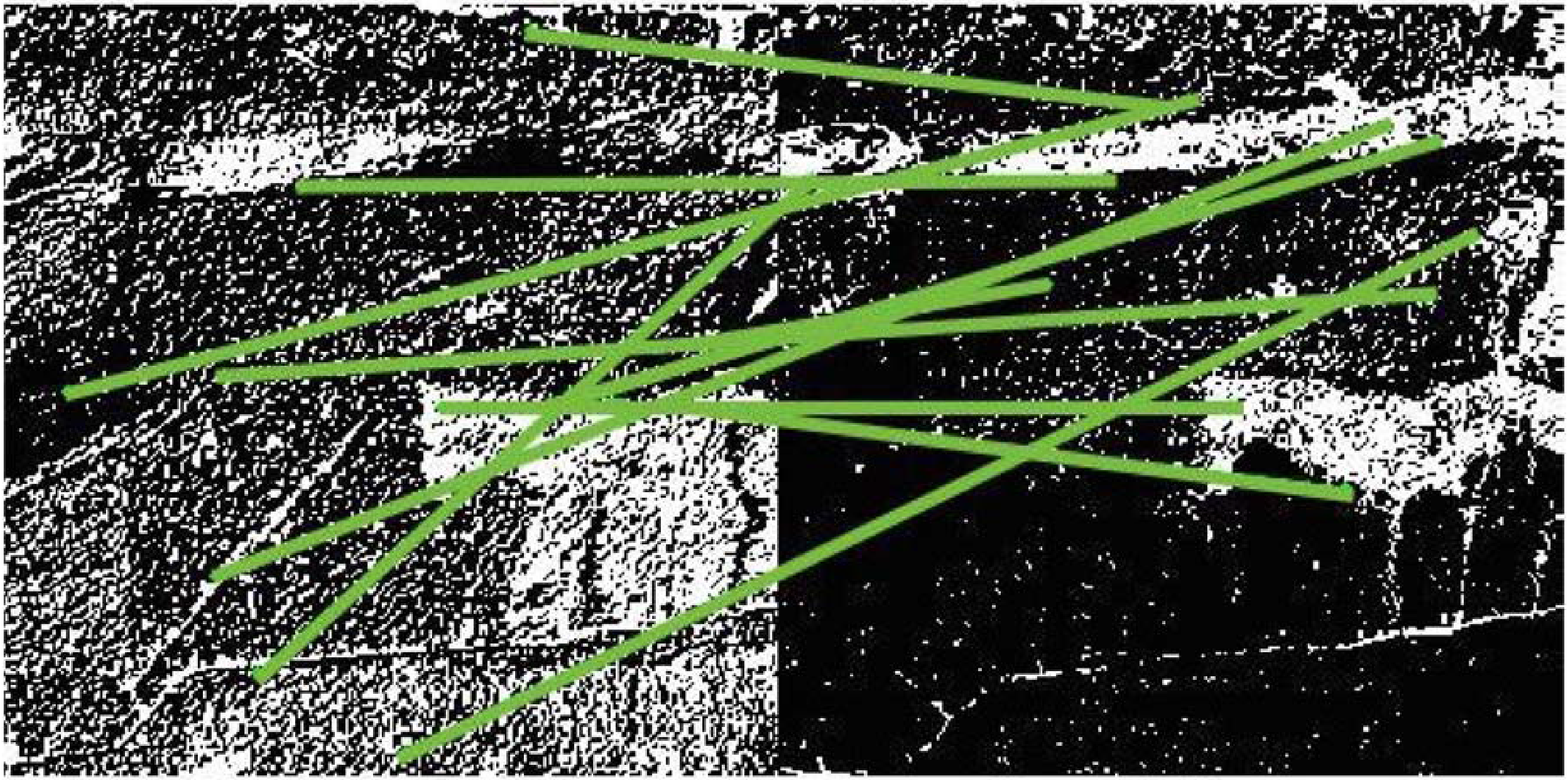
Derived Shaded Relief Image



Aerial photograph

Washington State Multimodal Observations:
The shaded relief image, which is illuminated in the same direction as in the optical image, depicts similar patterns of textures and edges.

Multimodal Image Registration Challenges

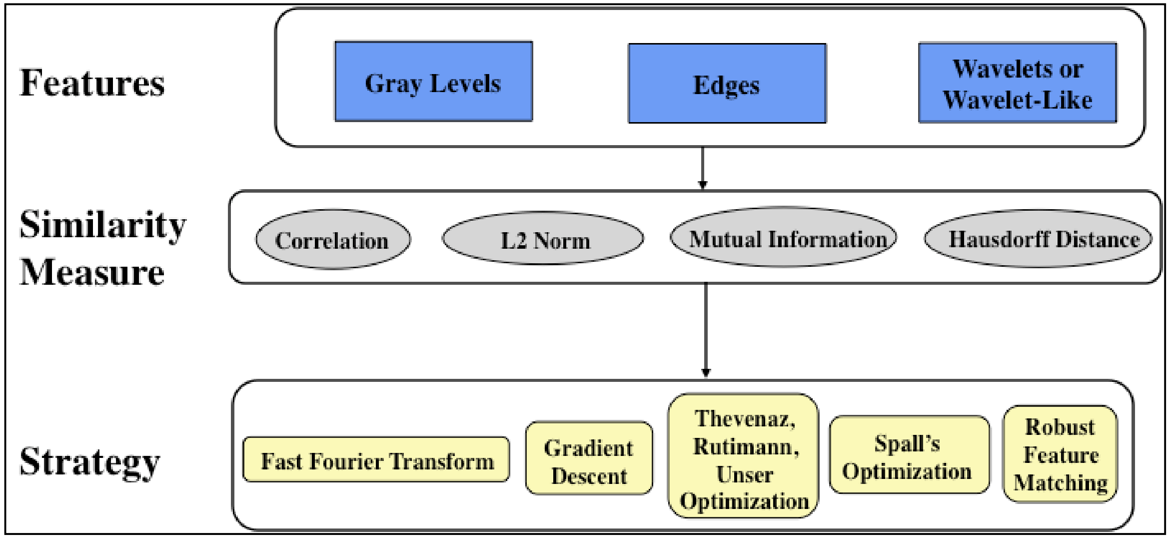


Pixels computed by SIFT in the LIDAR shaded-relief (left) and optical (right) images of Washington State, connected by line segments. Note the lack of correspondence; such points are unsuitable for a registration algorithm.

Previous Work

Wavelet and Shearlet Based Algorithms

Edge, Wavelet and Wavelet-Like Based Registration Framework

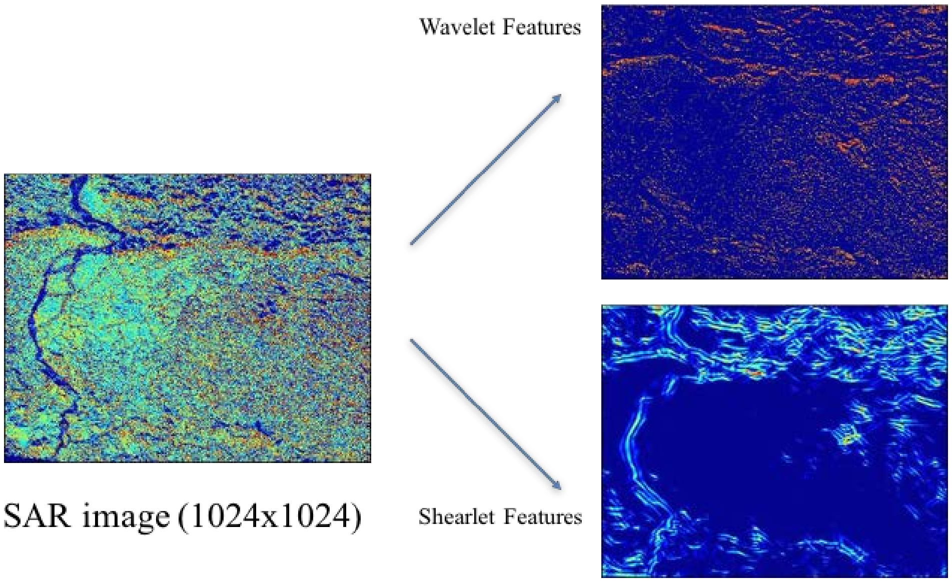


- Wavelets are fundamentally *isotropic*, i.e., no directional sensitivity
- Generalization of wavelets to be *anisotropic* => *Shearlets*, which ***refine the wavelet construction by including a directional component***

- Methods based on wavelets and shearlets:
  - o Effective for registration of most remotely-sensed images
  - o Challenged by texture-rich images and multi-modal image registration (e.g., LIDAR and optical)

Previous Work

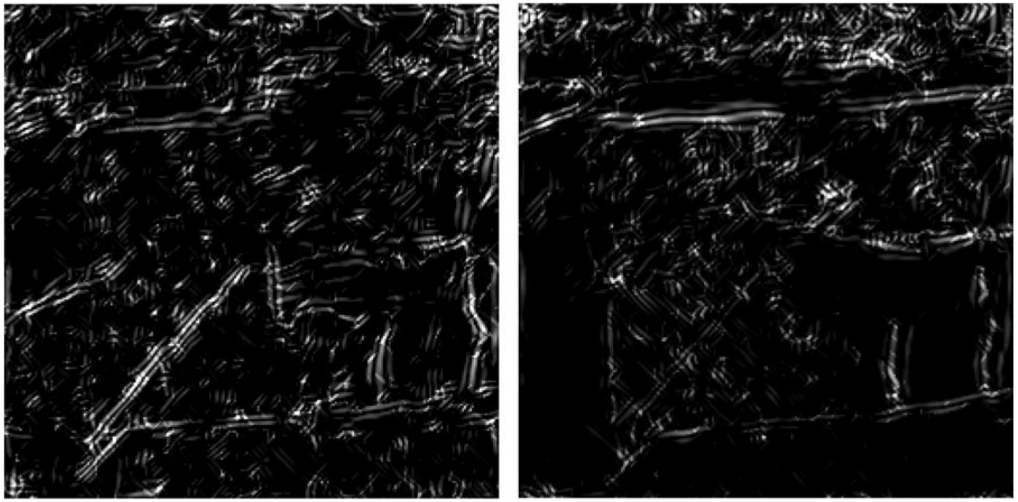
Wavelet and Shearlet Based Algorithms



SAR image (1024x1024)

Comparing Wavelet and Shearlet Features for a SAR Image

Shearlet features produced for Lidar shaded relief (left) and optical (right) images of Washington State



Strongest edge-like features are emphasized: a diagonal of trees for Lidar and land-cover change near the top for optical. Due to the information content differences between Lidar and optical data, these features are not represented in both images.

Shearlet-Based Registration Results

Lidar to Optical

Comparison of Registration Algorithms for LIDAR to Optical Multimodal Experiments

Registration Technique	Number of Converged Experiments (out of 101)	Percentage of Converged Experiments	Mean RMSE	Standard Deviation RMSE	Relative Improvement
Spline Wavelets	55	54.46%	3.4499	.0012	-
Simoncelli Band-Pass	61	60.40%	3.6542	.0174	-
Simoncelli Low-Pass	86	85.15%	3.5918	.0066	-
Shearlets	44	87.13%	15.6428	6.1668	-
Shearlet + Spline Wavelets	60	59.41%	3.4222	~ 0	9.09%
Shearlet + Simoncelli Band-Pass	65	64.36%	3.6518	.0174	6.56%
Shearlet + Simoncelli Low-Pass	88	87.13%	3.5912	.0083	2.33%

Shearlet-Based Registration Results

Infrared to NIR

Comparison of Registration Algorithms for ETM+ Infrared to NIR Multimodal Experiments

Registration Technique	Number of Converged Experiments (out of 41)	Percentage of Converged Experiments	Mean RMSE	Standard Deviation RMSE	Relative Improvement
Spline Wavelets	25	60.98%	.2389	.0137	-
Simoncelli Band-Pass	18	43.90%	.2492	~ 0	-
Simoncelli Low-Pass	34	82.93%	.2100	~ 0	-
Shearlets	38	92.68%	.6678	.3917	-
Shearlet+ Spline Wavelets	38	92.68%	.2465	.0336	52.00%
Shearlet+ Simoncelli Band-Pass	38	92.68%	.2492	~ 0	111.11%
Shearlet + Simoncelli Low-Pass	38	92.68%	.2100	~ 0	11.76%

Gabor Functions and Frames

- Gabor function: special case of Short-Time Fourier Transform

$$G_x(t,f) = \int_{-\infty}^{\infty} e^{-\pi(\tau-t)^2} e^{-j2\pi f\tau} x(\tau)d\tau$$

- Discrete Gabor Transformation:

$$g(t) = \sum_{m=-\infty}^{m=\infty} \sum_{n=-\infty}^{n=\infty} c_{mn} f(t - m\tau_0). e^{j2\pi nt/N}$$

- Frame: A set of functions which is "overcomplete" (w/r to a basis that is "complete"). A frame can achieve a decomposition of a space that is more stable and more robust than a basis.

- Discrete directional Gabor frames vs. Wavelets:
  - Better at representing images where texture is the dominant feature
  - Capture texture features and their direction

Directional Gabor Frames (DGF)

- Elements of the form:

  $$g_{m,n,u}(x) \ := g^{m,n}(u\,.\,x);\ m\ and\ n\ \in\ \mathbb{R}, u\ \in\ S^{d-1}, x\ \in\ \mathbb{R}^d$$

  for a given function $g:\ \mathbb{R} \rightarrow \mathbb{C}$

  => Directional Gabor Frame: $\{g_{m,n,u}\}_{(m,n,u)\in\Lambda}$

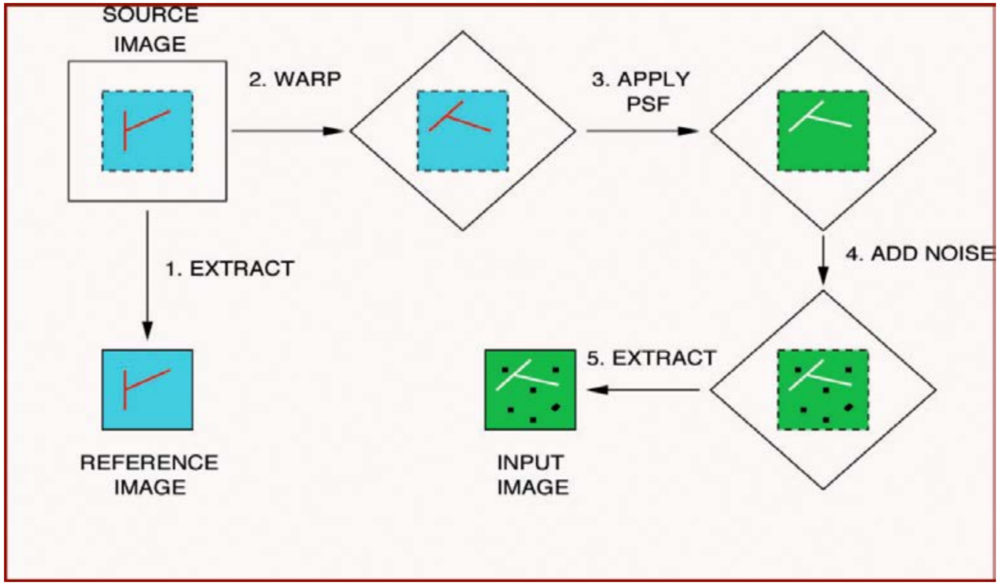
- Choice of $g(x) = sinc\left(\frac{x}{16}\right)^4$

  with the compact support $K = \left[-\frac{1}{4}, \frac{1}{4}\right]$

- Assuming a $2M \times 2N$ image,

  $$(m,n) \in [0,2M-1] \times [0,2N-1]$$

Preliminary Registration Experiments Using DGF

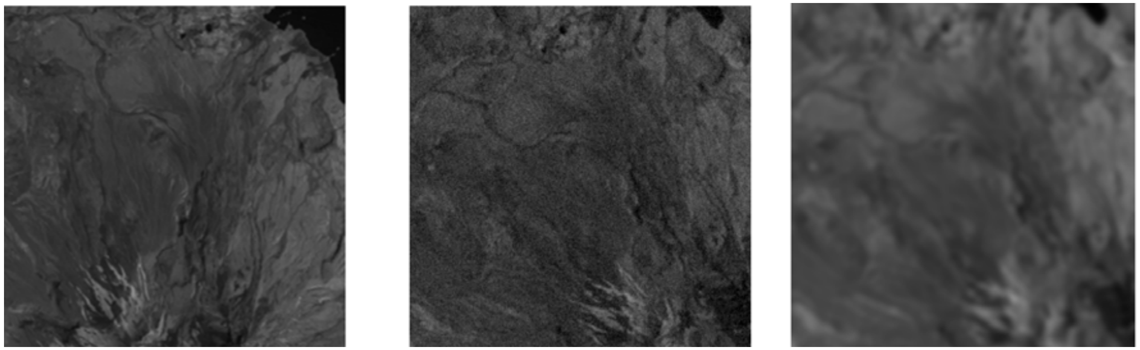


Synthetic Image Generation

Transformation of Starting Scene:

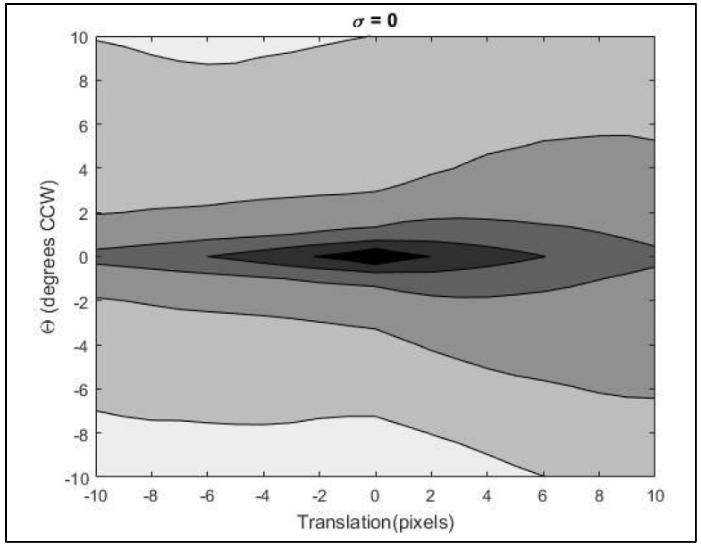
- Scales in [0.8,1.2] (step = 0.05)
- Translations in [0,20] pixels (step = 0.5)
- Rotations in [0,20] degrees (step = 0.5)
- Gaussian noise in [-15, 20] dB (step = 1)
- Radiometric Transformation (PSF constructed from black 512x512 image with 5x5 white center)

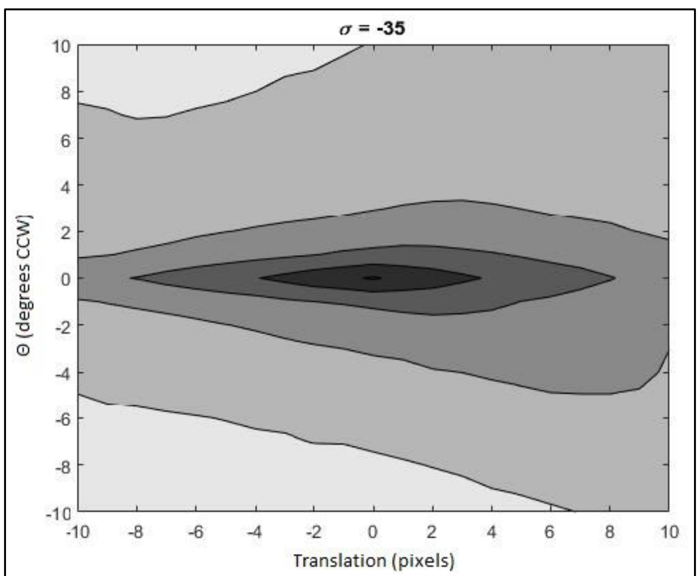
[Zavorin and Le Moigne, 2005]

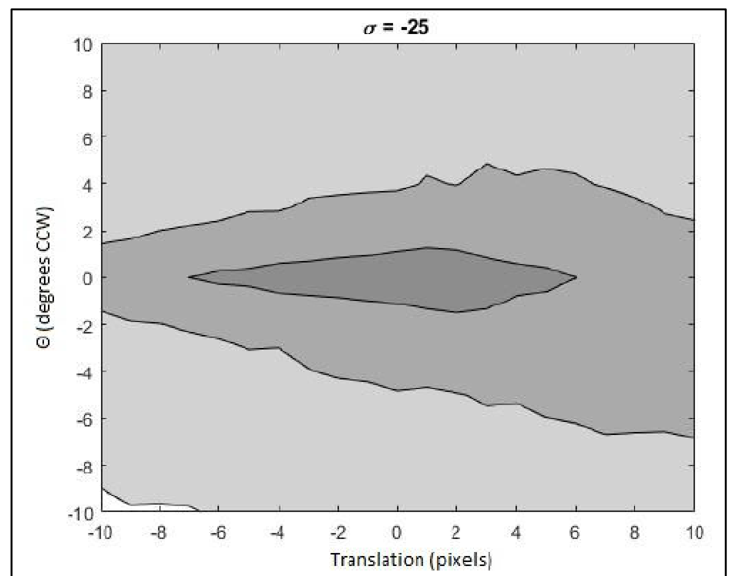


Synthetic Image Examples (Original; Warp & Noise; Warp & PSF)

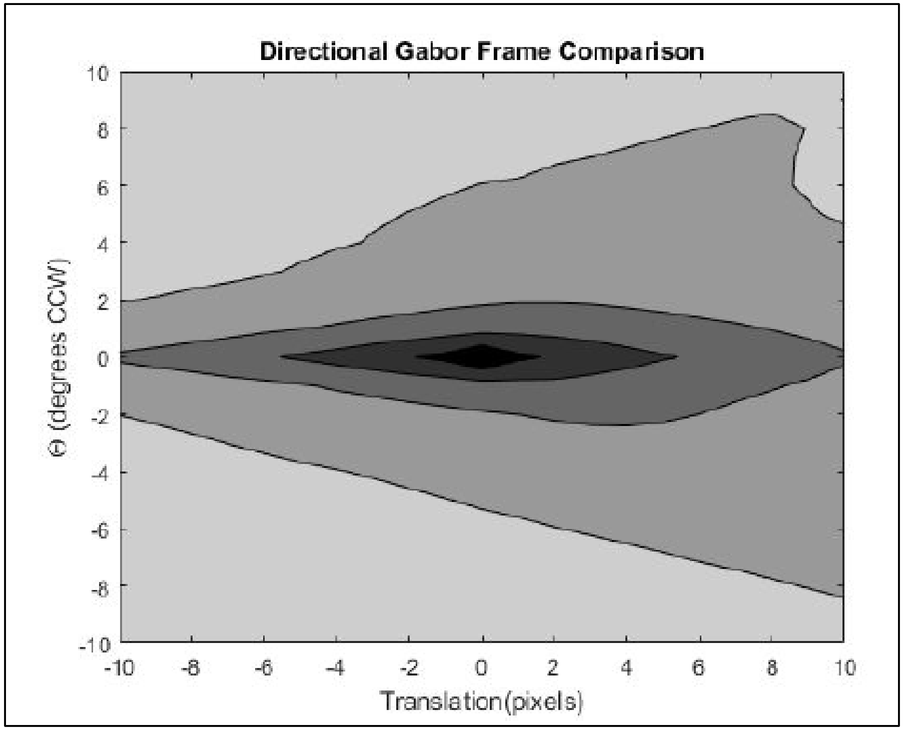
Preliminary Registration Experiments Using DGF – Translation & Noise

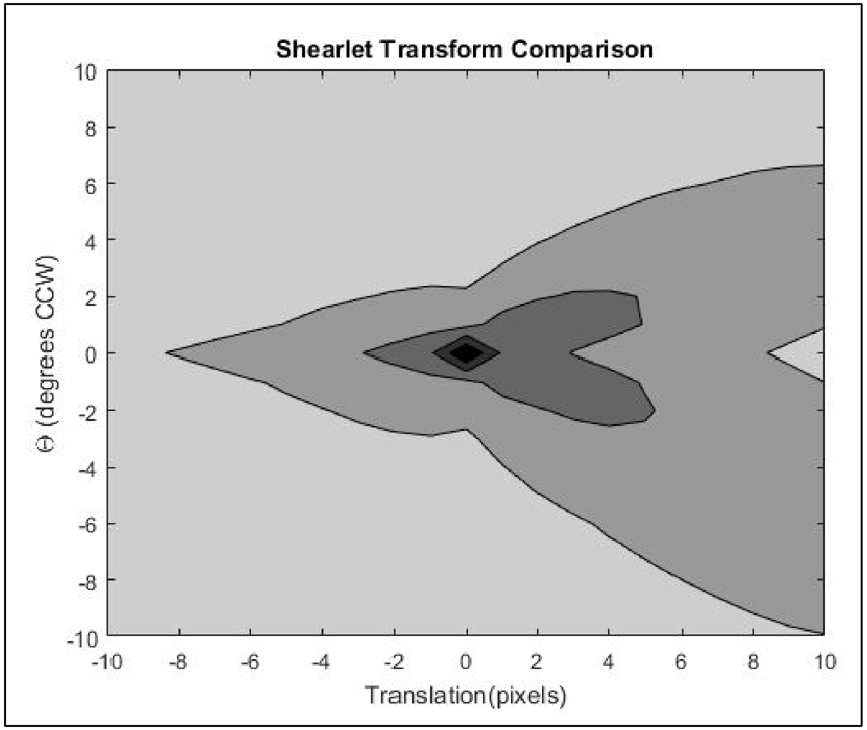






Preliminary Registration Experiments Comparing DGF and Shearlets





Conclusions

- Preliminary experiments using Directional Gabor Frames looking at the accuracy of the registration with respect to various translations and various amounts of noise.
- Errors obtained with Directional Gabor Frames appear to be lower than the errors obtained with Shearlets for larger values of rotations and translations.
- Further experiments need to be performed for:
  - Systematic variations of rotations, translations, noise, and with varying radiometries
  - Various initial conditions
  - Various multi-sensor datasets, including Lidar, Thermal IR and NIR data
  - Systematic comparison with various wavelets, shearlets and other registration methods