Image Registration using an Optimization Algorithm for Images preprocessed by Histogram Matching

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Problem Statement

- To investigate the benefits of using the optimization algorithm to register
  - a Synthetic Vision System (SVS) image, which has been preprocessed using histogram matching

  to
  - an image from a Forward Looking Infrared Radar (FLIR) sensor, which is onboard an aircraft.

Image Registration using Mutual Information

Image Registration

- is the process of determining the set of parameters (tx, ty, θ, sc) that produce the most accurate match between a pair of images.

Mutual Information (MI)

- is the measure we use to determine the similarity between the pair of images. The higher the MI value, the better the match.

Mutual Information

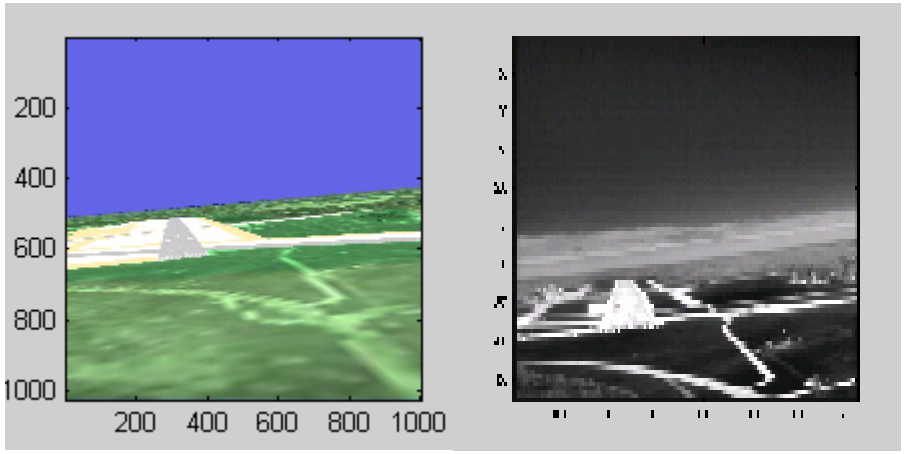
is defined by:

$$I(A,B)=\sum_{a,b} P_{AB}(a,b).\log\left(\frac{P_{AB}(a,b)}{P_A(a).P_B(b)}\right)$$

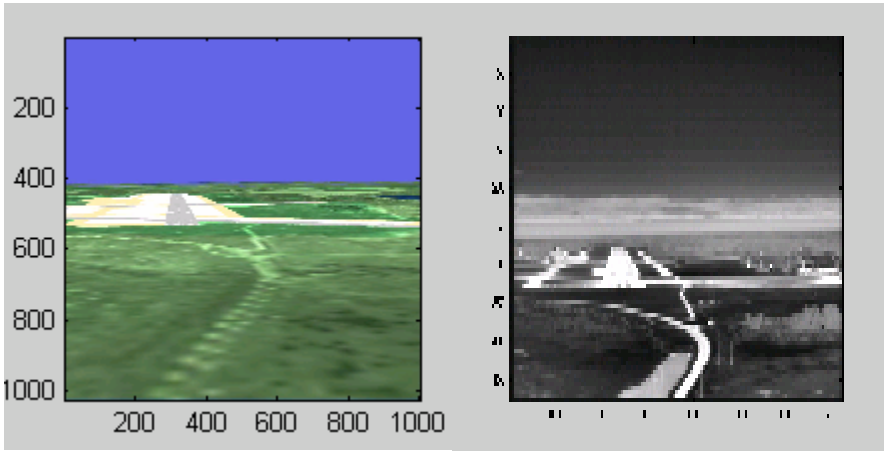
where A represents the FLIR image and
B represents the SVS image.

- The probability distributions $P_A^{(a)}$ and $P_B^{(b)}$ are computed using the histograms, $h_A(a)$ and $h_B(b)$,of the image intensities of A and B.
- $P_{AB}^{(a,b)}$ is computed using the joint histogram, $h_{AB}(a, b)$.

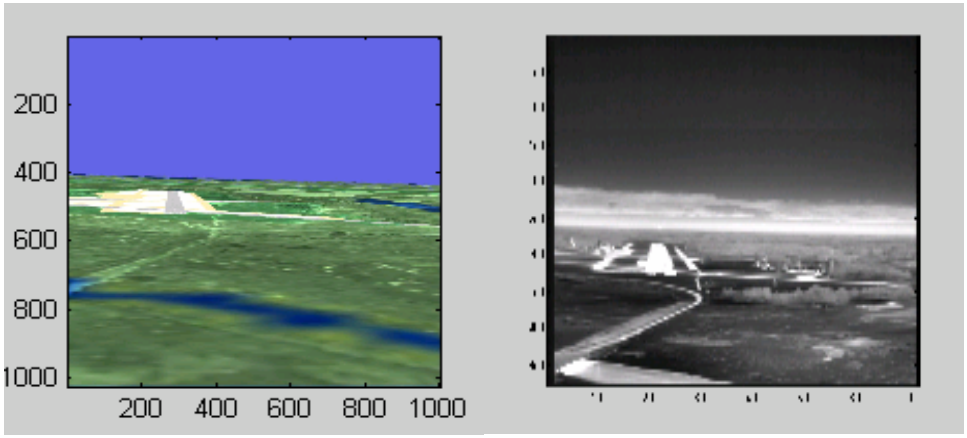
Image Pairs to be Registered



at 160 ft



at 200 ft



at 300 ft

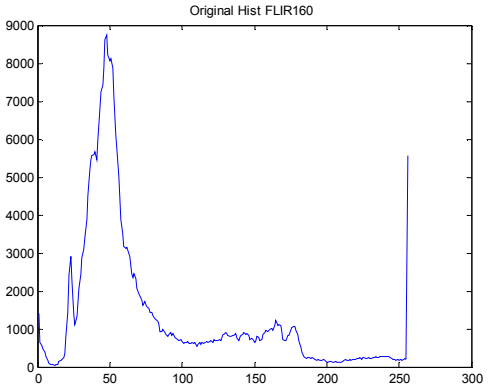
Image Pre-processing using Histogram Matching

- Histogram Matching is applied to the SVS images before registration to enhance the performance of the registration algorithm.

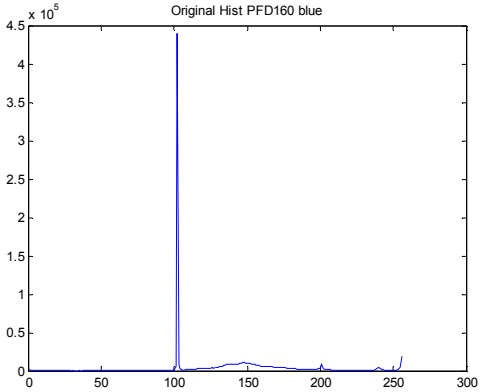
- Two preprocessing methods are compared:
  - Histogram Matching (only)
  - Histogram Matching with a Wavelet Decomposition (Method 2)

Histogram Matching

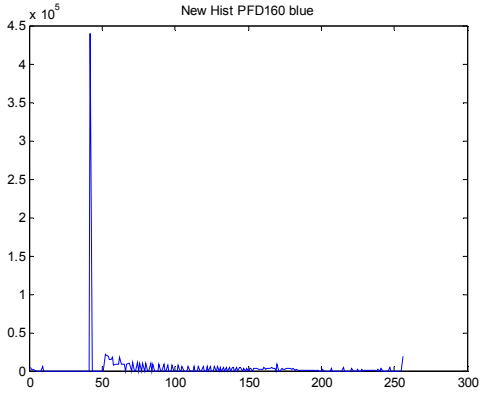
- uses a distribution provided an image.
- modifies the histogram of the SVS image to be similar to the histogram produced by the FLIR image.



FLIR Histogram



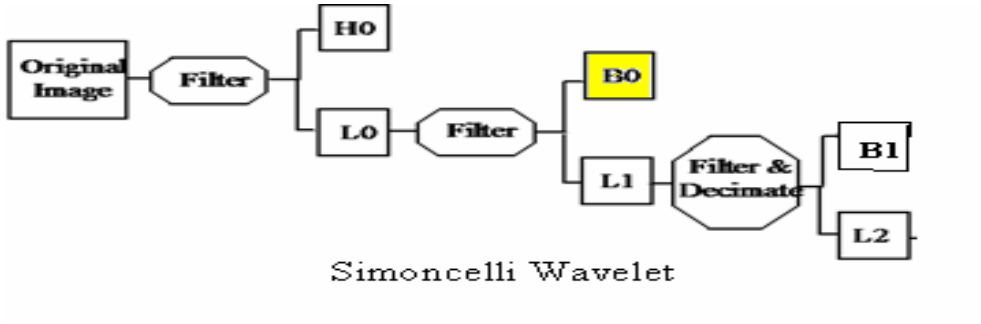
Original Blue Band Histogram



New Blue Band Histogram

Method 2:

Histogram Matching After Simoncelli Wavelet Decomposition



Method 2 consists of the following steps:

- Decompose SVS image to Level 0.
- Crop image to 480x480.
- Apply Histogram Matching to the SVS.
- Register the final SVS against FLIR image.

Search Methodologies

1) *Exhaustive Search Technique*

- A range and an increment must be chosen for each parameter, (tx, ty, θ, sc).
- The reference image is transformed using all parameter combinations within the range, and MI is calculated.
- The parameter combination with the highest MI is chosen as the registration point.

Disadvantage: Slow process

Search Methodologies

2) *Optimization Algorithm*

- is a hill climbing (steepest ascent) algorithm used to determine where MI is maximized.
- requires a starting point and total number of iterations must be provided.

$$p_{k+1} = p_k + a_k \; g_k(p_k)$$

where a_k is step-size, g_k is the gradient, and $p_k = (tx, ty, \theta, sc)$, at iteration k.

Advantage:

- Faster method
- More accurate

Results for *Histogram Matching* at 160ft

Exhaustive Search

FLIR 160 / SVS160	Tx	Ty	Theta	Scale	MI (float)
Blue	152	-71	1	0.52	1.0711
Green	153	-81	2	0.52	0.9299
Red	152	-68	1	0.52	1.0565

Results for *Histogram Matching* at 160ft

Optimization for the Blue Band

	Tx	**Ty**	**Theta**	**Sc**	**MI Value**	**Max Itera.**
Starting Point	***151***	***-75***	***1***	***0.5***	***1.0099***	
Original	151.874	-75.748	1.070	0.517	1.0715	347
Basic 1	151.984	-75.114	0.874	0.522	1.0715	117
Alt 2A (x5)	152.300	-75.262	0.952	0.519	1.073	18
Alt 2B (x20)	152.769	-77.126	1.162	0.516	1.068	108
Alt 2C (x50)	151.586	-75.029	0.974	0.524	1.0753	90
Alt 2D (x75)	151.778	-75.024	1.160704	0.529	1.07237	275
Alt 2E (x100)	152.110	-71.127	0.949	0.528	1.07693	80

Blue Optimization Results, Starting Point 1

Results for *Method 2* at 160ft

Exhaustive Search

FLIR 160 / SVS160	Tx	Ty	Theta	Scale	MI (float)
Blue	151	-82	1.0	0.52	0.4154
Green	152	-70	1.0	0.54	0.3893
Red	153	-66	1.0	0.54	0.3941

Results for *Method 2* at 160ft

Optimization for the Blue Band

	Tx	**Ty**	**Theta**	**Sc**	**MI Value**	**Max Itera.**
Starting Point	***152***	***-80***	***1***	***0.5***	***0.37122***	
Original	150.991	-80.445	0.537	0.513	0.40393	339
Basic 1	151.706	-80.140	0.993	0.525	0.42136	235
Alt 2A (x5)	152.331	-79.651	0.947	0.527	0.41939	227
Alt 2B (x20)	152.327	-81.979	0.955	0.526	0.4207	336
Alt 2C (x50)	152.905	-84.681	1.176	0.525	0.41552	313
Alt 2D (x75)	150.581	-93.916	0.759	0.513	0.4052	30
Alt 2E (x100)	152	-80	1	0.5	0.37122	0

Blue Optimization Results, Starting Point 2

Conclusion for Images at 160ft

- For both Histogram Matching and Method 2
  - the blue band produced the best results.
  - the green and red optimization results moves towards blue results.
- For Histogram Matching, step-size x100 (Alt2E) produced the best results.
- For Method 2, step-size x20 (Alt2B) produced the best results.

Results for *Histogram Matching* at 200ft

Exhaustive Search

	Tx	Ty	Theta	Sc	MI (Float Code)
Blue	155	-9	0	0.6	0.66359
Green	155	-13	0	0.6	0.50897
Red	151	-45	0	0.68	0.56714

Results for *Histogram Matching* at 200ft

Optimization for the Blue Band

	Tx	**Ty**	**Theta**	**Sc**	**MI Value**	**Max Itera.**
Starting Point 1	***155***	***-9***	***0***	***0.6***	***0.66384***	
Original	154.829	-9.089	-0.041	0.6009	0.67102	92
Basic 1	154.417	-9.194	0.155	0.6002	0.67174	312
Alt 2A (x5)	154.557	-9.928	0.171	0.601	0.67301	216
Alt 2B (x50)	153.872	-11.132	0.004	0.592	0.67304	51
Alt 2C (x100)	154.552	-10.877	-0.765	0.594	0.66397	138
Alt 2D (x75)	155.012	-10.393	0.146	0.603	0.66731	349

Blue Optimization Results, Starting Point

Results for *Method 2* at 200ft

Exhaustive Search Results

	Tx	**Ty**	**Theta**	**Sc**	**MI Value (float)**
Blue	150	-21	0	0.56	0.191369
Green	135	-50	0	0.40	0.217533
Red	150	-20	0	0.56	0.187363

Results for *Method 2* at 200ft

Optimization for the Blue Band

	Tx	**Ty**	**Theta**	**Sc**	**MI Value**	**Max Itera.**
Starting Point	***145***	***-15***	***0***	***0.5***	***0.13859***	
Original	145.028	-14.989	-0.033	0.500	0.16828	10
Basic 1	145.042	-15.083	-0.107	0.525	0.16577	325
Alt 2A (x5)	145.992	-15.195	0.000	0.537	0.17280	270
Alt 2B (x20)	146.356	-15.339	-0.097	0.540	0.17565	262
Alt 2C (x50)	151.330	-14.077	0.215	0.569	0.19234	192
Alt 2D (x75)	152.959	-10.783	0.008	0.579	0.18023	303
Alt 2E (x100)	149.902	-14.566	0.440	0.563	0.17957	51

Blue Optimization Results, Starting Point 2

Conclusion for Images at 200ft

- For Histogram matching, the blue band produced the best results.
- For Method 2, the blue and red band produced consistent results.
- For both methods, there was no consistent step-size alteration which produced the best registration point.

Results for *Histogram Matching* at 300ft

Exhaustive Search

FLIR300 / SVS300	Tx	Ty	Theta	Scale	MI (float)
Blue	160	-9	0	0.6	0.51955
Green	158	-19	0	0.6	0.40908
Red	157	-14	0	0.58	0.47005

Results for Histogram Matching at 300ft

Optimization for the Blue Band

	Tx	**Ty**	**Theta**	**Sc**	**MI Value**	**Max Itera.**
Starting Point	***162***	***-15***	***0***	***0.56***	***0.34542***	
Original	158.392	-15.987	-0.050	0.586	0.51455	308
Basic 1	160.904	-14.650	-0.484	0.606	0.49865	337
Alt 2A (x5)	158.769	-14.112	0.016	0.596	0.52660	233
Alt 2B (x20)	157.905	-14.734	0.344	0.594	0.52055	113
Alt 2C (x50)	159.174	-8.553	-0.548	0.594	0.53292	110
Alt 2D (x75)	158.713	-14.745	0.011	0.597	0.52279	29
Alt 2E (x100)	157.665	-12.217	0.637	0.588	0.51626	33

Blue Optimization Results, Starting Point 2

Conclusions

Histogram matching at 300ft

- The blue band worked the best.
- There was no consistent step-size alteration which produced the best registration point.

Overall Conclusion

- The blue band worked consistently well for all the images tested from 160-300ft, when using both preprocessing methods.

Future Work

- Apply optimization algorithm to the Method 2 images at 300ft and higher altitudes.
- Use different step-sizes in the optimization algorithm to improve on the exhaustive search results.

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