TU Delft GEODELTA

Dynamic Seamless Oblique Image Mosaics for Aerial Visualization

Final Assessment (P5)

Master of Geomatics | Xiaoluo Gong

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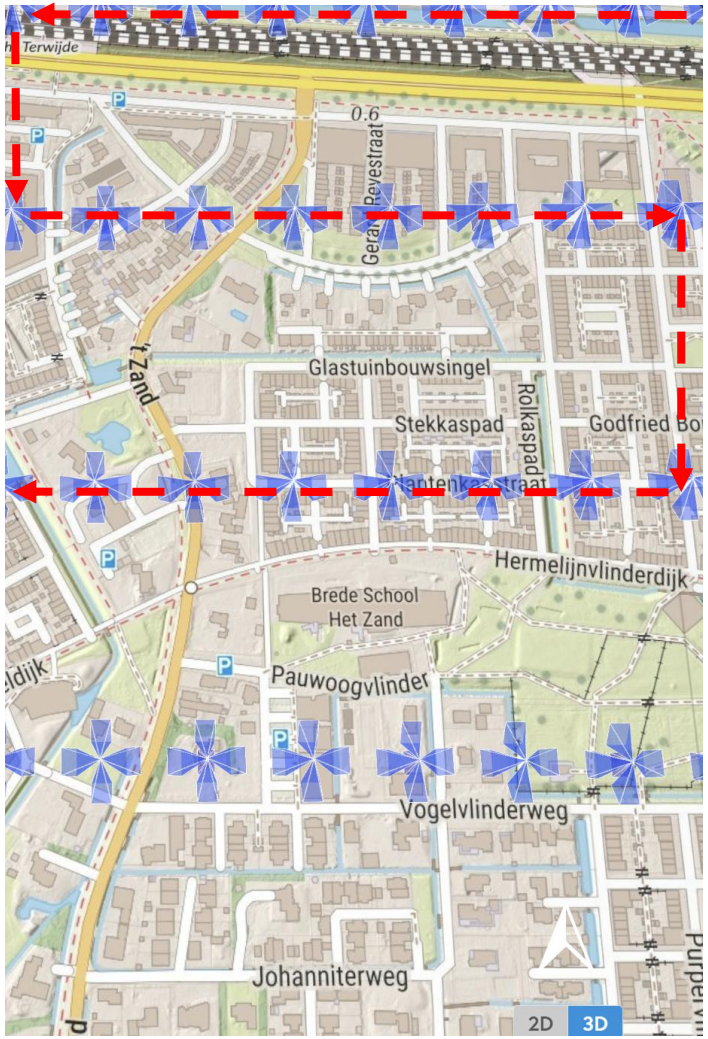
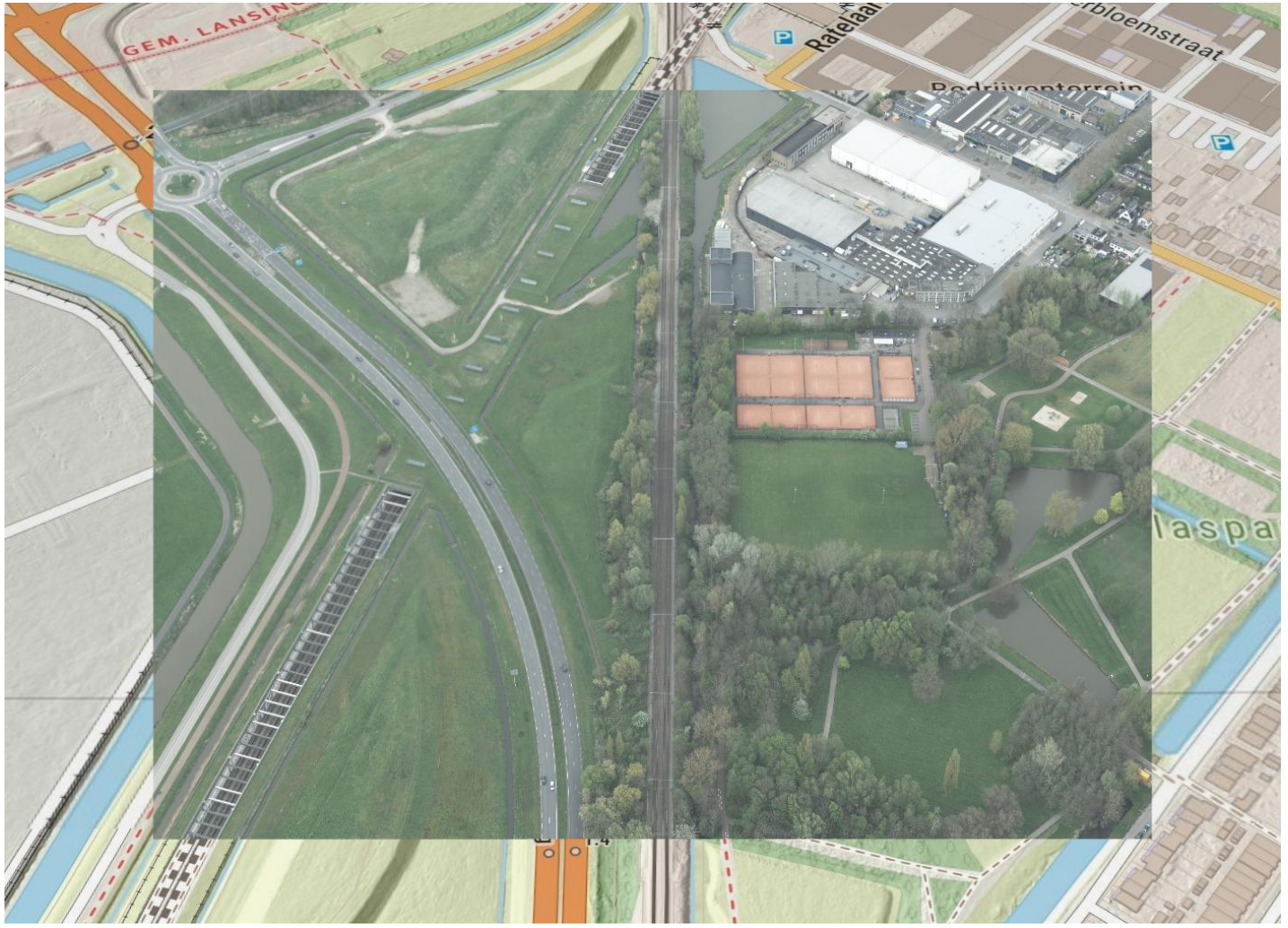
01

Problem Overview

The Current Oblique Image Visualization in Omnibase



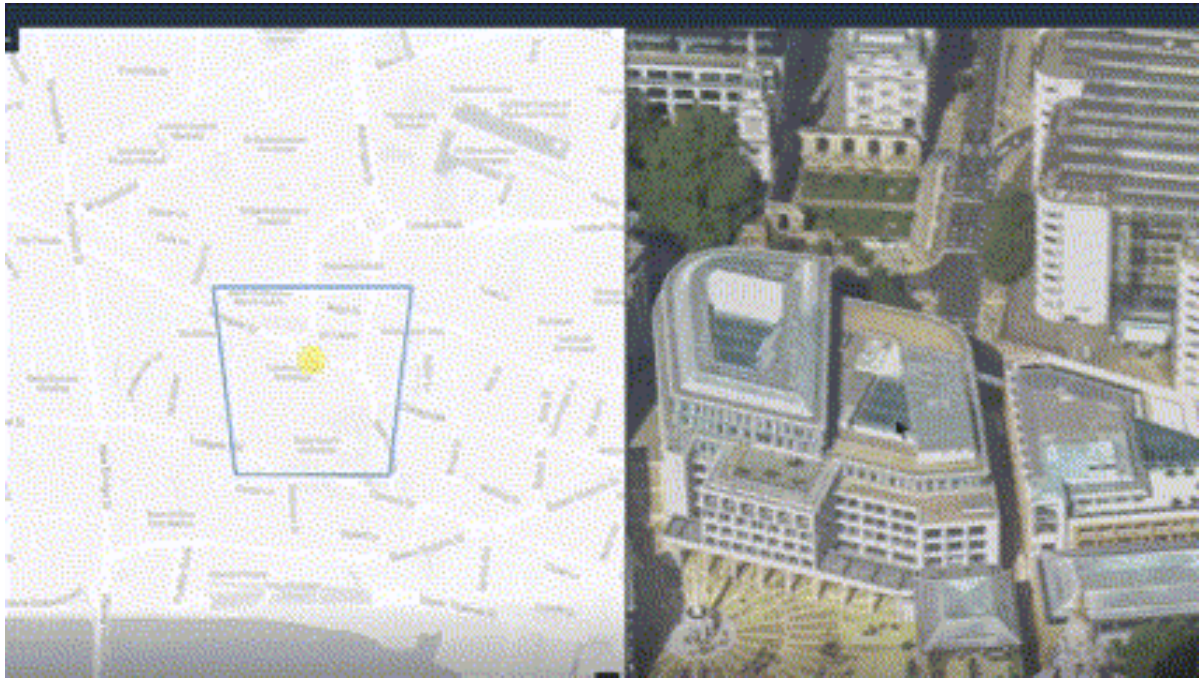


(adopted from Omnibase)

flight lines

Definition of Dynamic Image Stitching

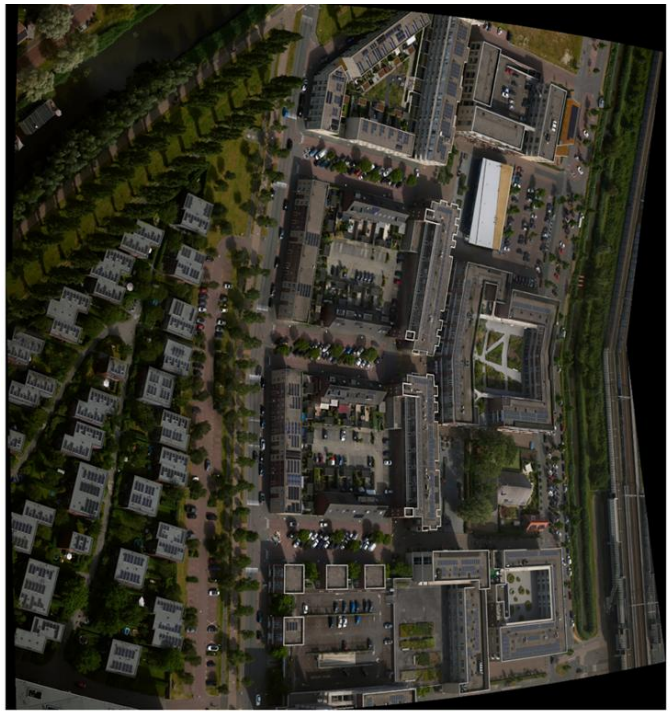
Why NOT Just Stitching them ALL?



Continuous transition from one image to another

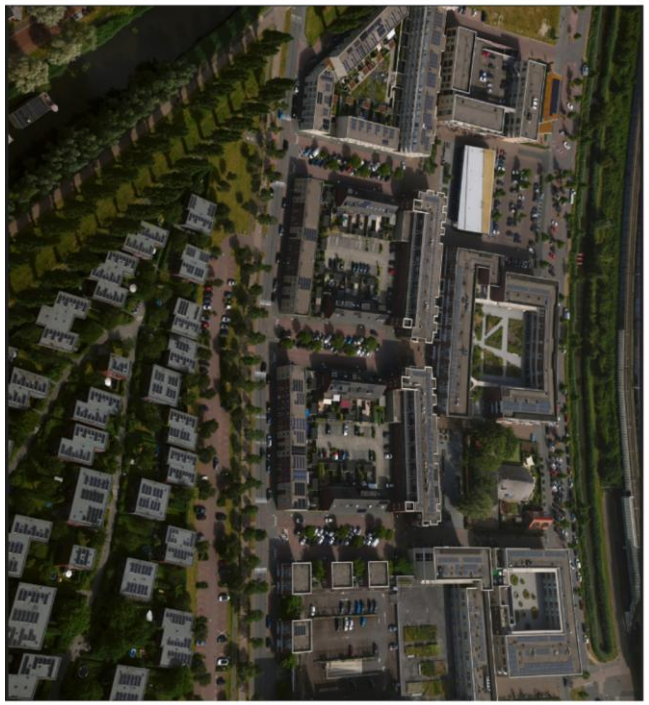
(adopted from: Xmap)

Existing Image Stitching Software



AutoStitch

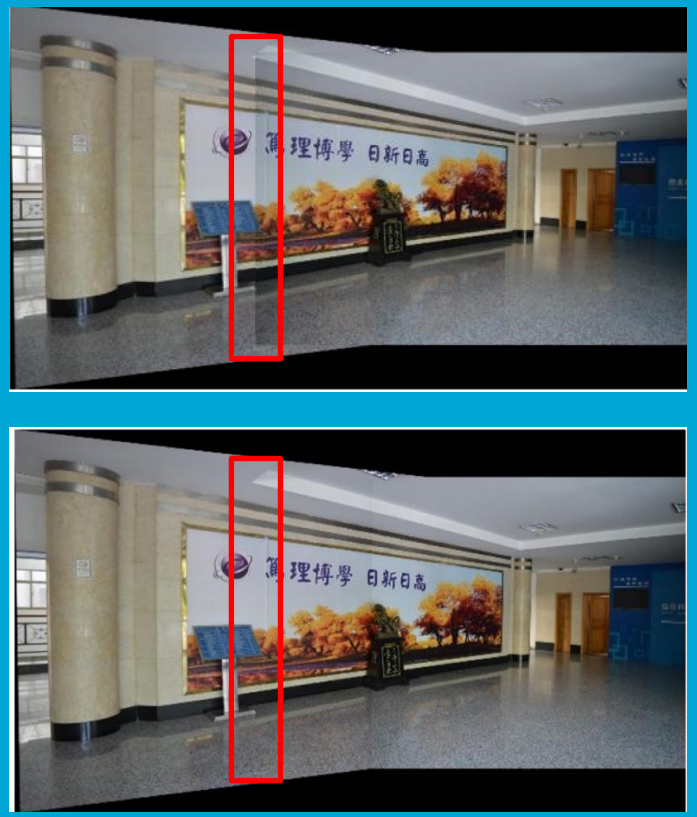
PTGui



Hugin

- **Slow**
- **Not Reductive**
- **Not keep the straight lines**

Seamless



(adopted from Wang et al,(2020))

Smooth

(adopted from Google Map)

Measurable

(adopted from Omnibase)

Goals to achieve!

02

Methodology & Definitions

Types of Image Stitching Techniques

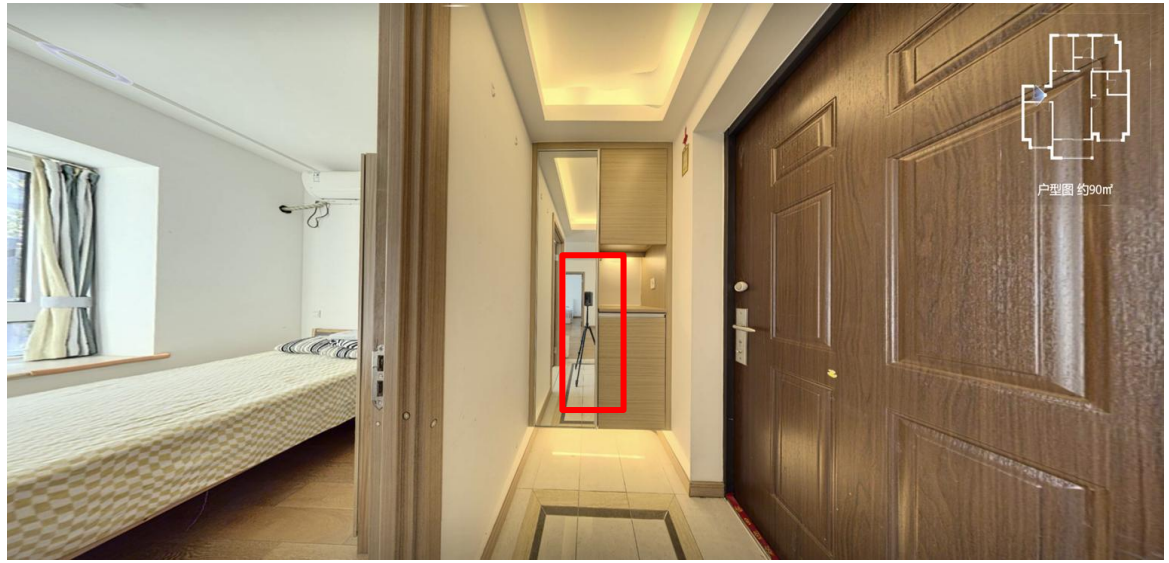
TABLE I
COMPARISON OF MOSAIC AND PANORAMA STITCHING METHODS

Stitching method	imaging dimension	depth information	Relative movement between cameras	viewpoint
Mosaic stitching	2D	Ture	Exist	Fixed
Panorama stitching	2.5D	Fake	No-exist	Movement

All 57 images aligned

Final result

(adopted from AutoStitch)



(adopted from Ke.com)

Image Stitching: combine images together

Image Warp: digitally manipulating an image

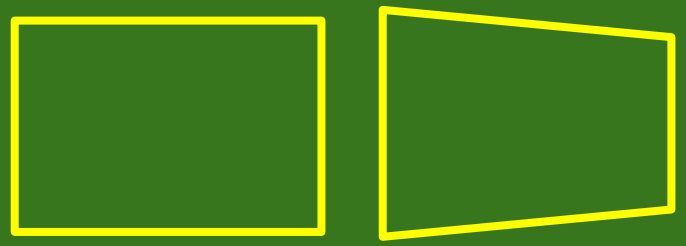
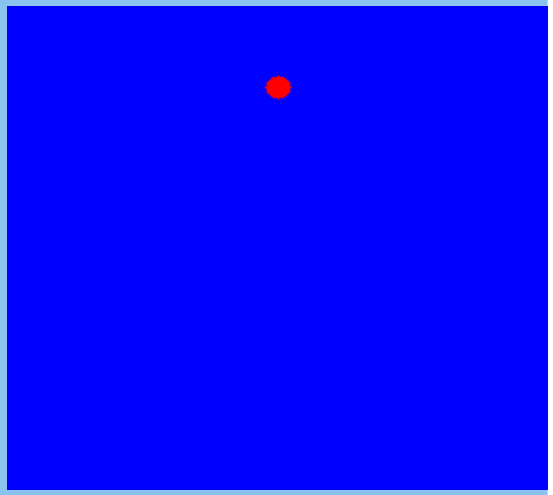
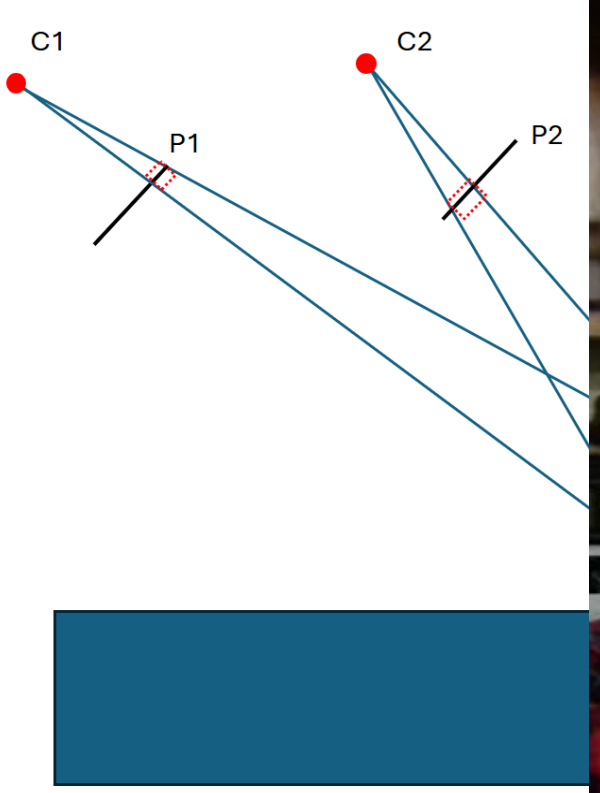


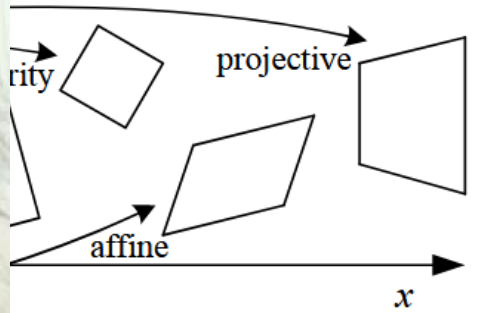
Image Morphing: smooth transition between images.



What kind of warp to do?



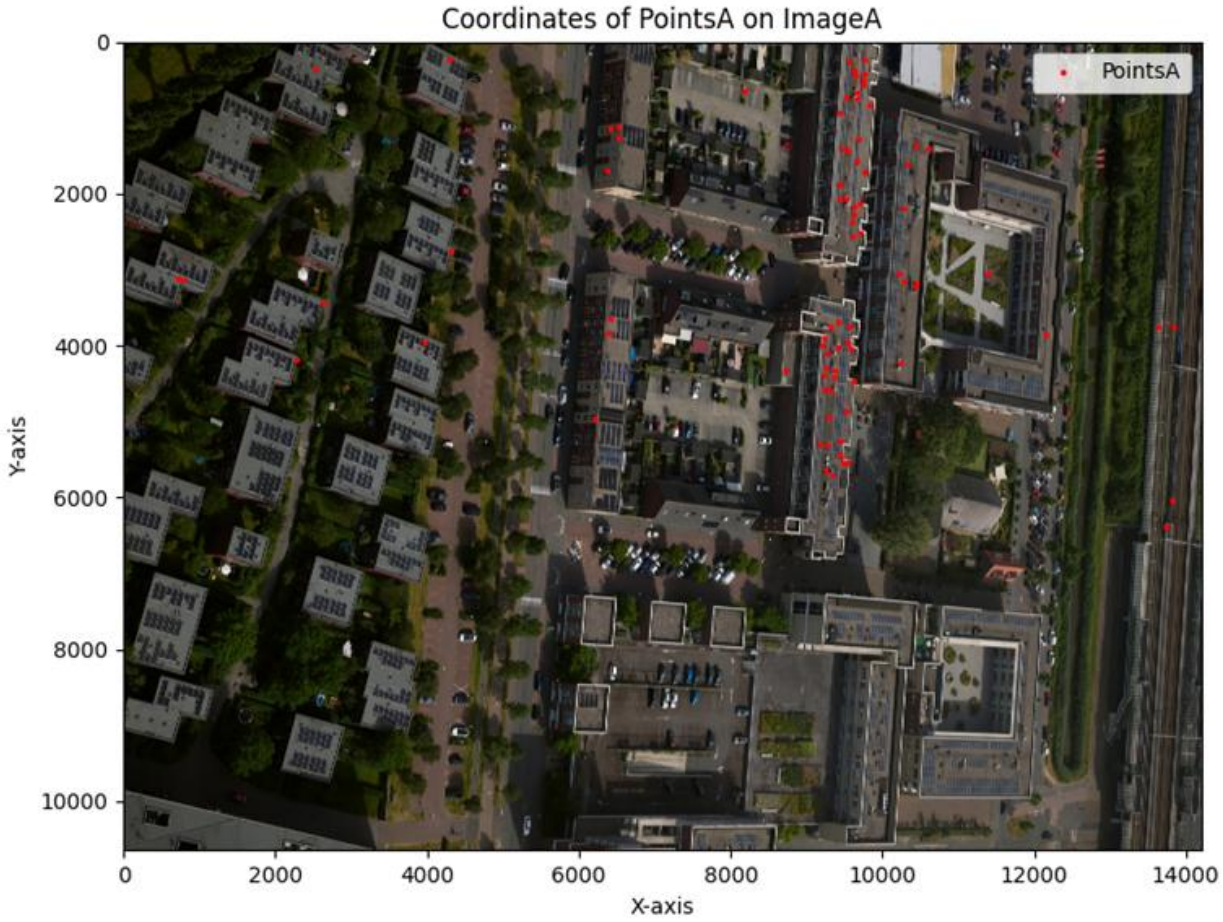
$$\begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix}$$



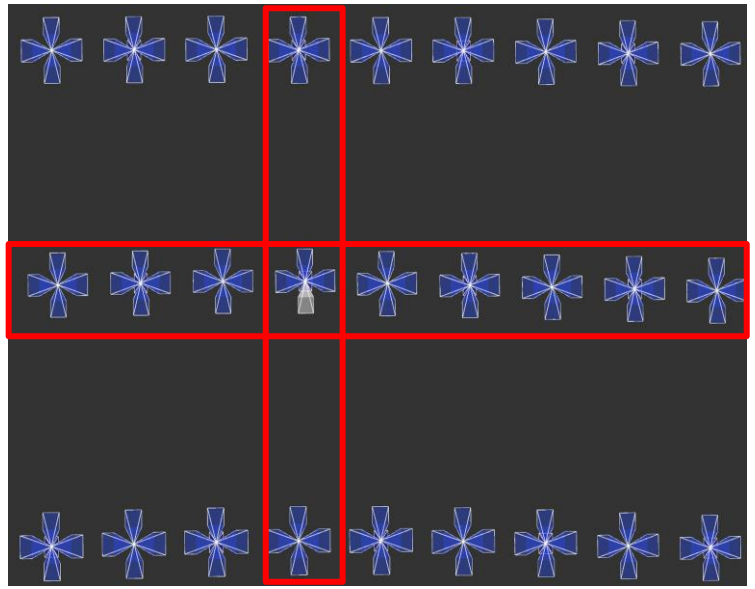
transformation:

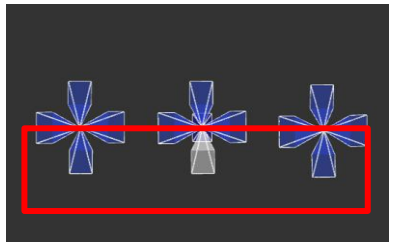
ormation from other

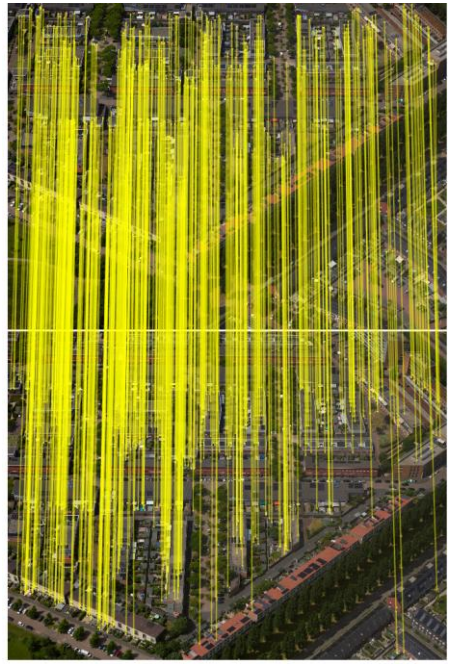
(adopted from: Wikipedia)

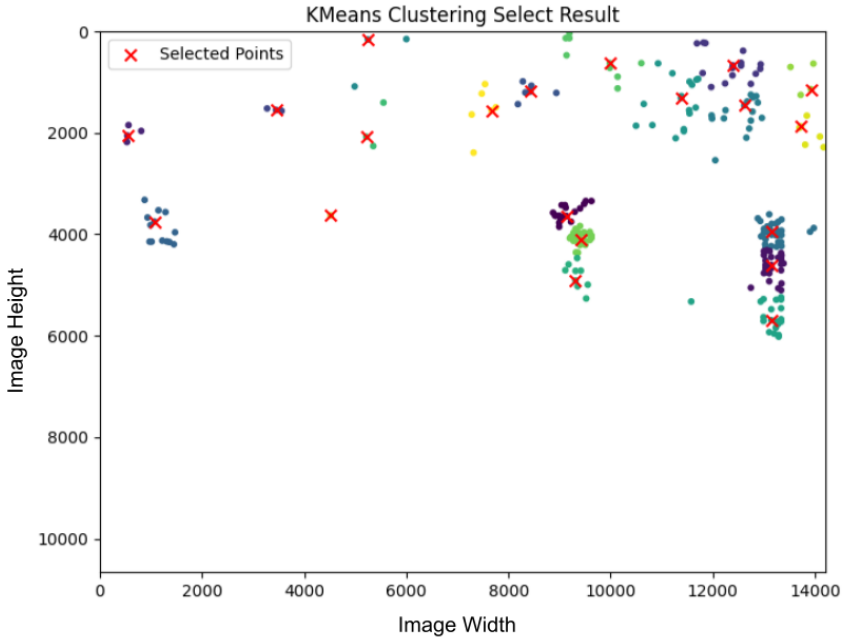


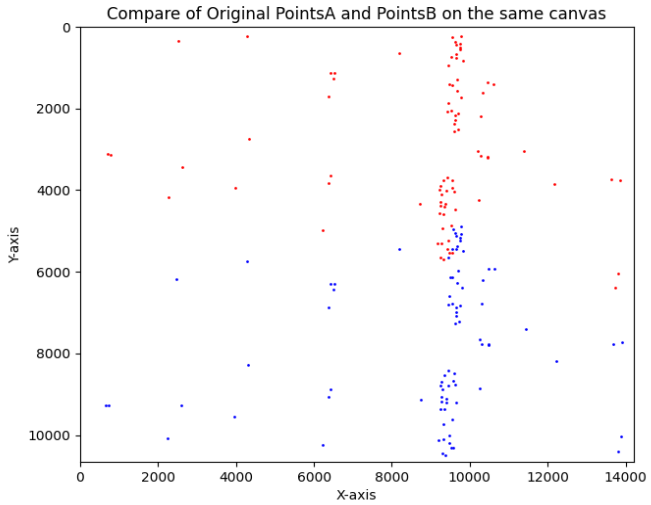
Feature points - Tie points

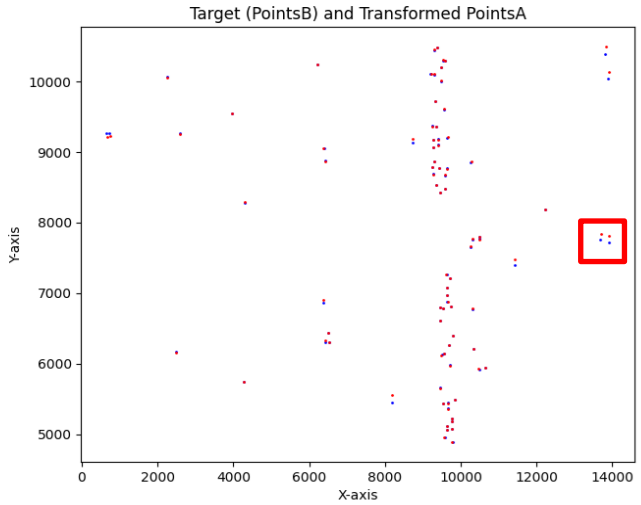




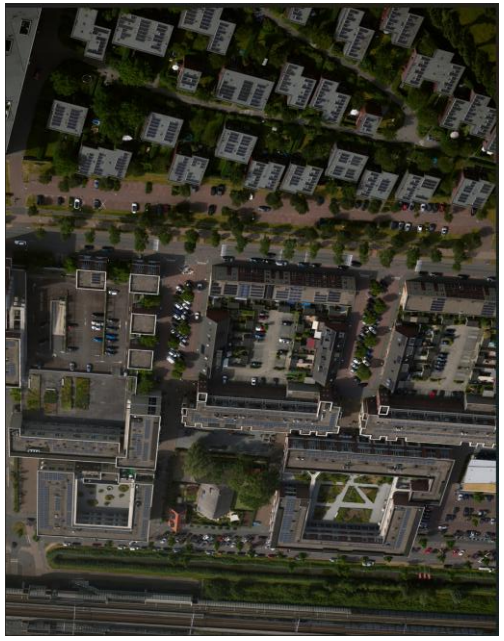



KMeans Clustering Select Result
Selected Points
Image Height
Image Width
0
2000
4000
6000
8000
10000
12000
14000



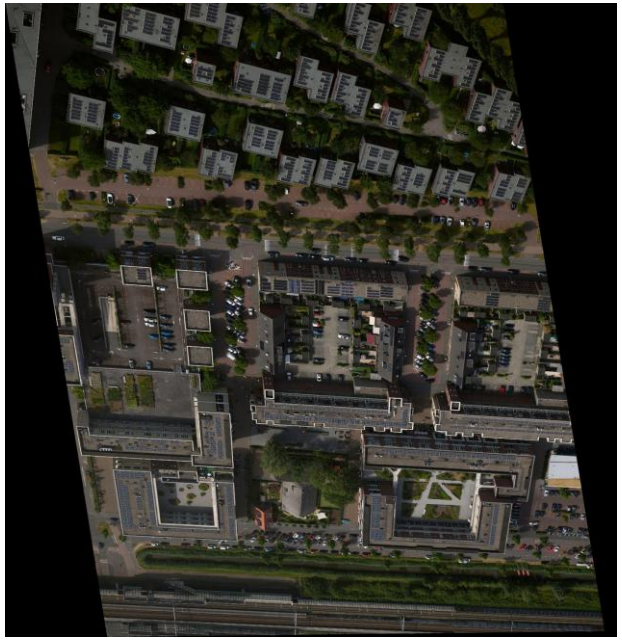


RMSE Calculation

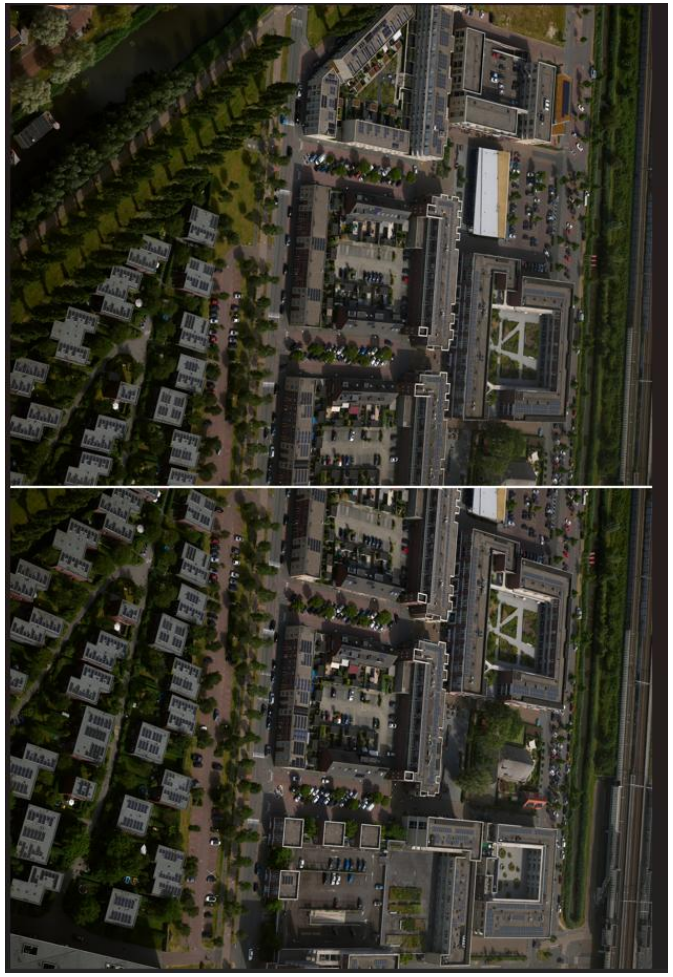


$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix}$$

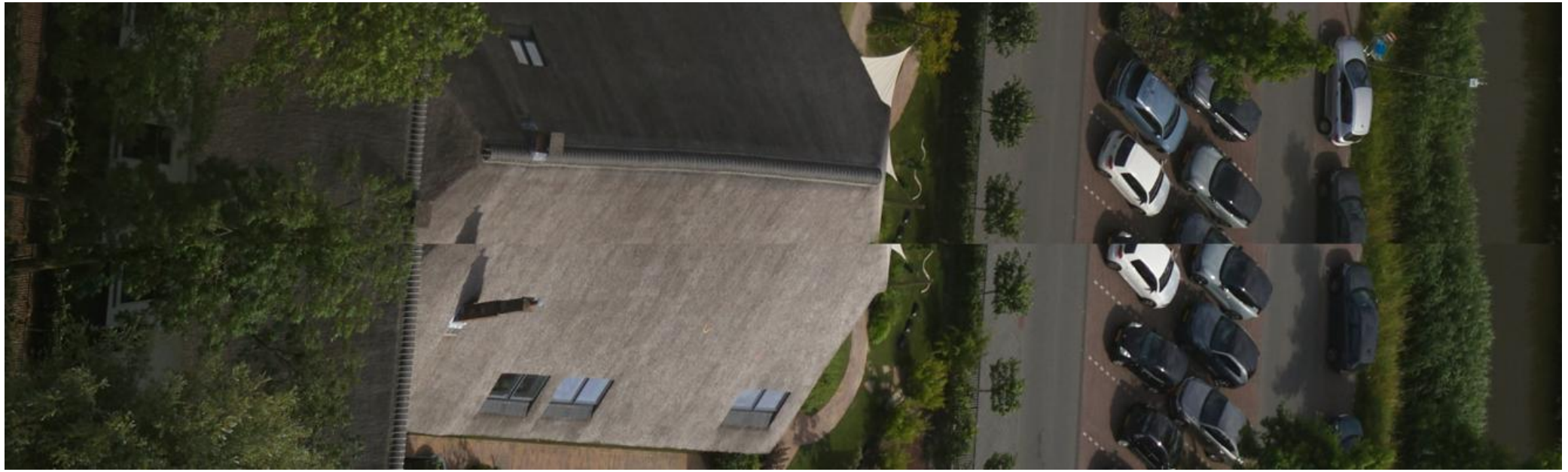
Interpolation?



Initial Result by Simply Overlay the Warped Image

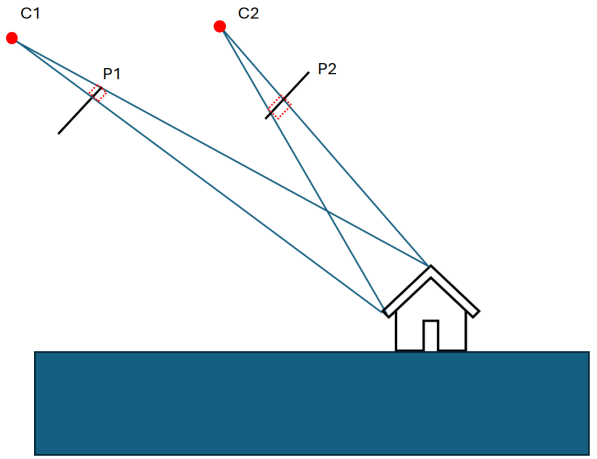


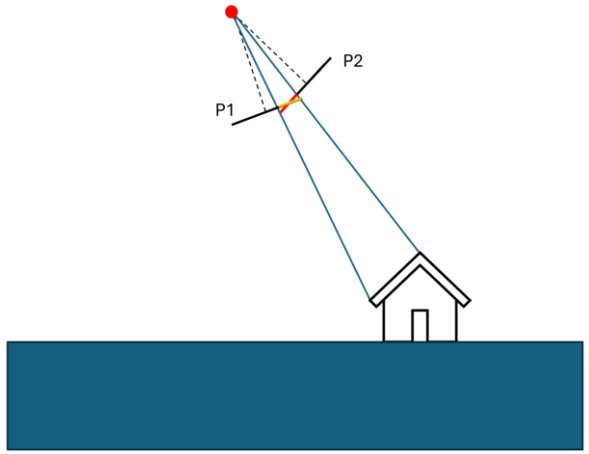
Can oblique aerial image really be modelled by a single homography matrix?



- **Duplicated objects**
- **Broken rooftop…**

Can oblique aerial image really be modelled by a single homography matrix?





$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix}$$

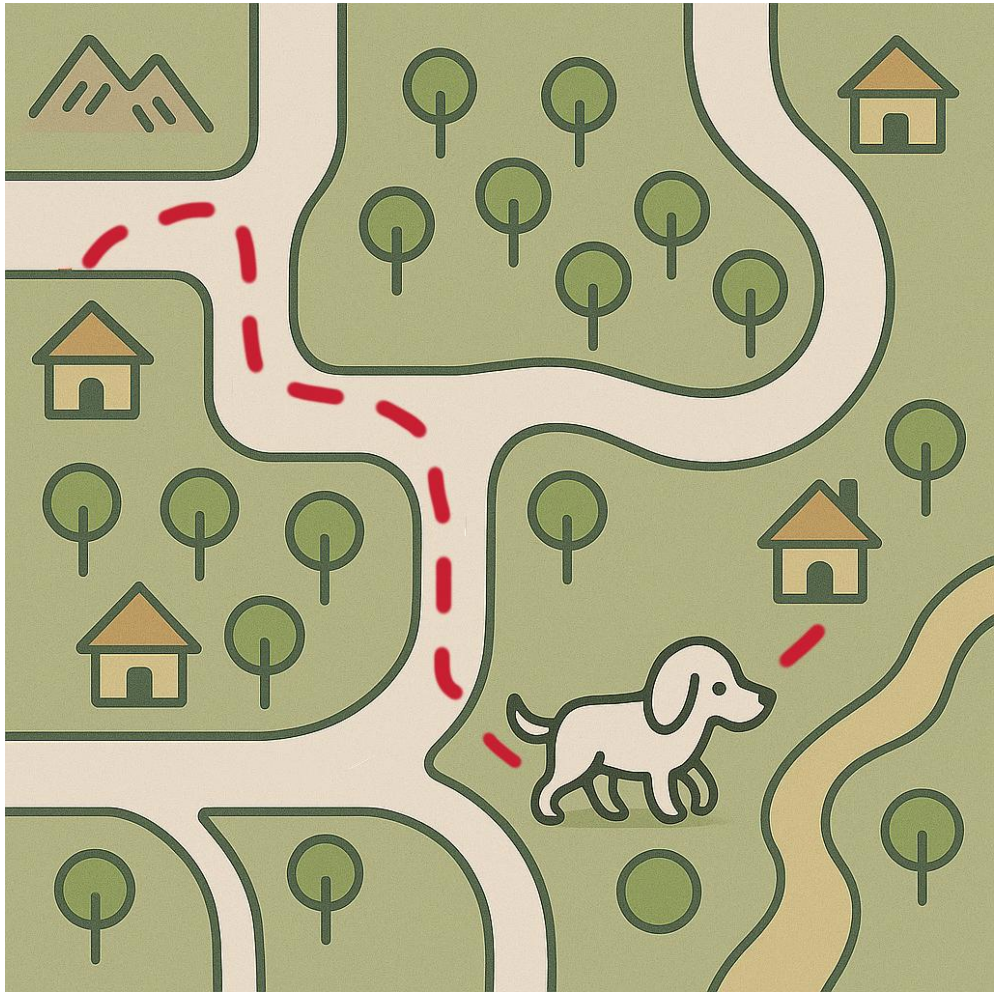
$$[x, y, 1\ ]^T$$

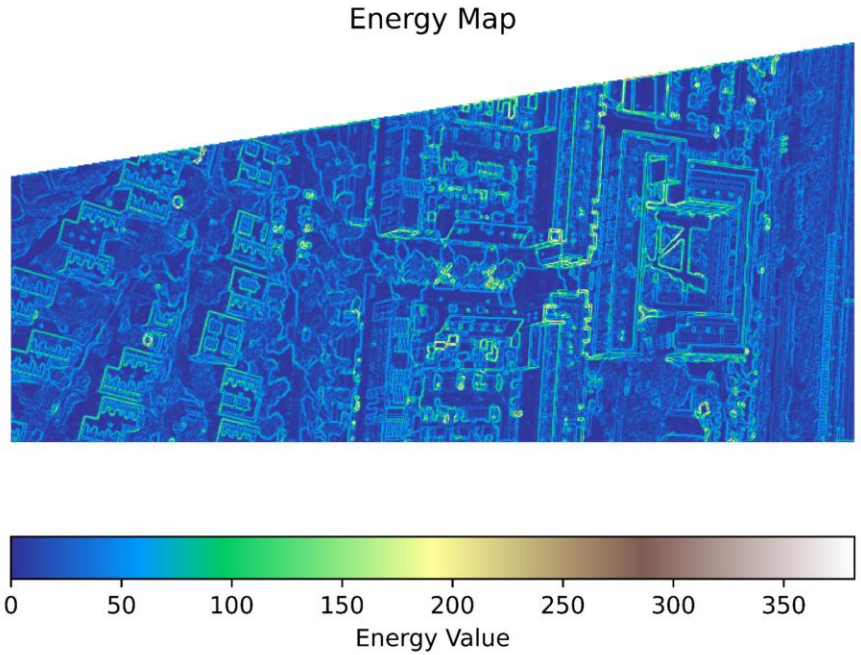
$$M_{10} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[x, y, z, 1\ ]^T$$

Optimal Seam : Avoid Going to the “Rooftops”

- **Protect the objects we want to measure or view**
- **Reduce the error caused by elevation changes**
- **Hide the seam**





7	4	8	5	7
3	7	NaN	5	4
8	8	3	6	5
2	NaN	6	0	8
1	6	9	1	3

Input Image
(Energy Map)

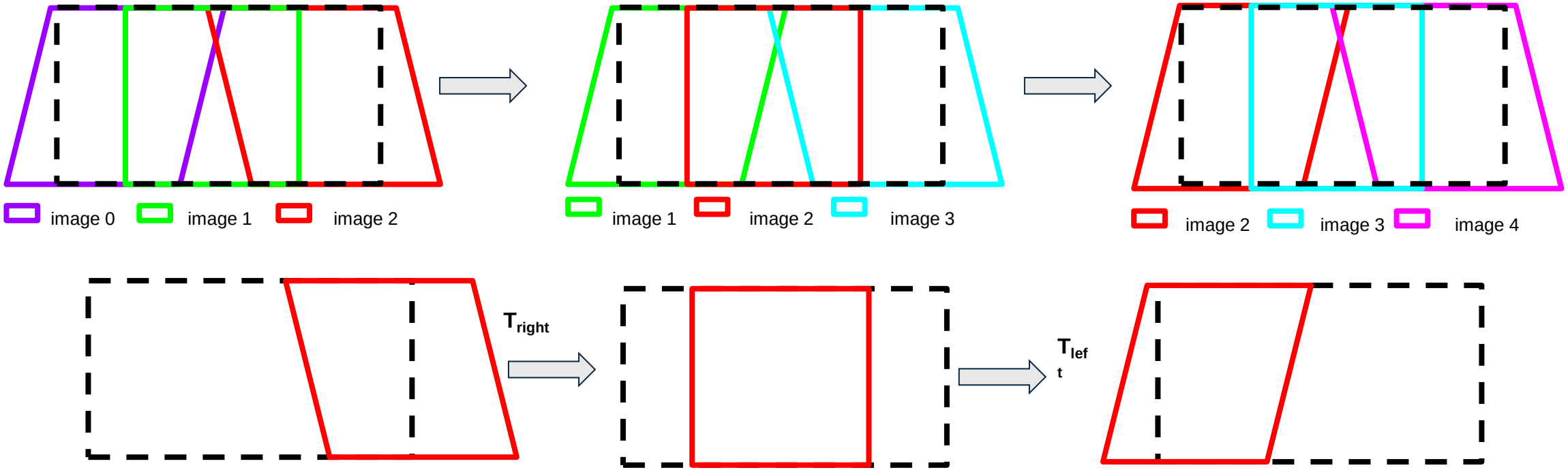
7	7	15	20	27
3	10	inf	18	22
8	10	13	19	18
2	inf	16	13	21
1	7	16	17	16

Dynamic Programming Matrix
$O(H \times W)$

-1	1	0	0	0
-1	1	-1	0	1
-1	3	2	2	3
-1	-1	2	2	3
-1	4	4	4	3

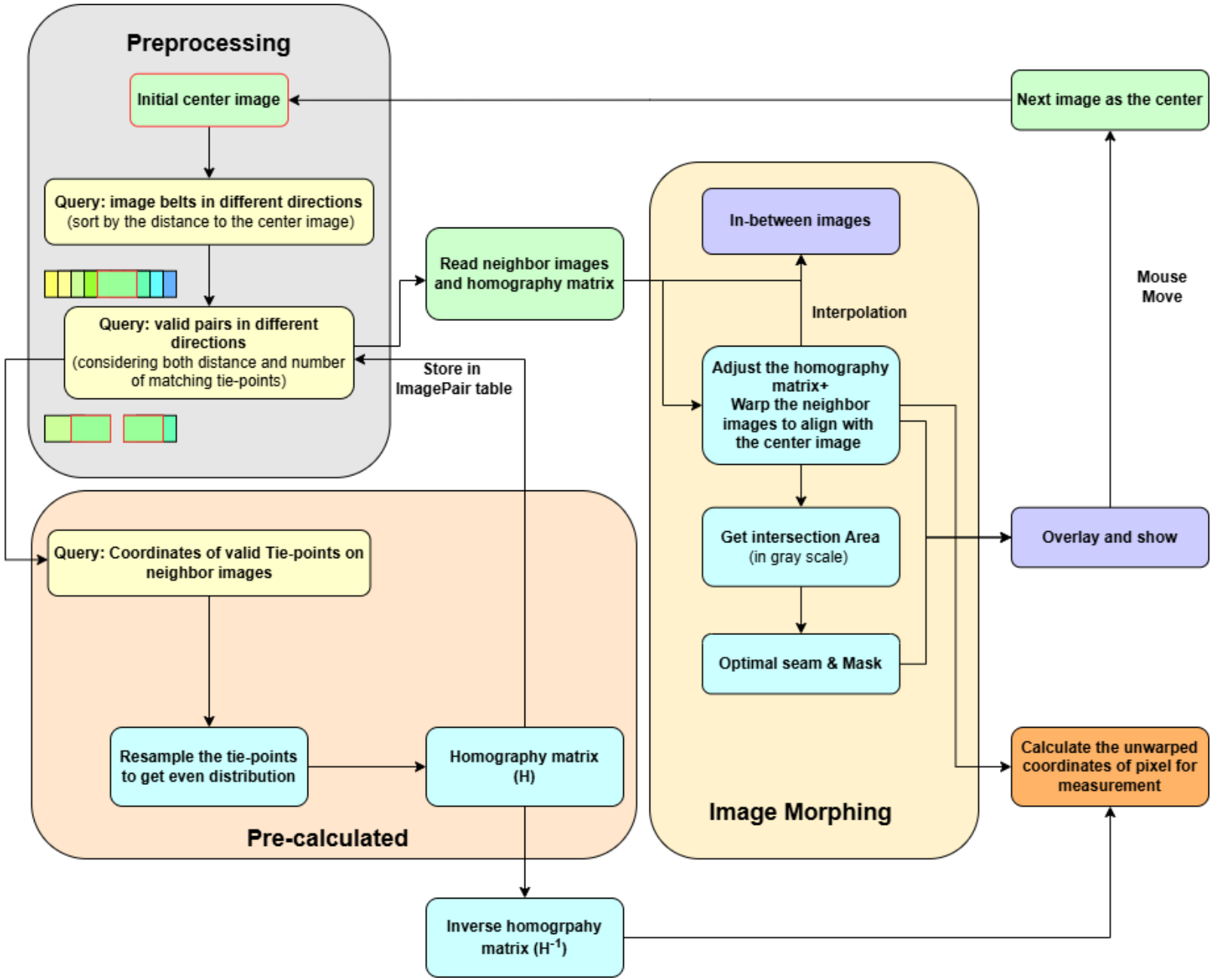
Backtrack Matrix

How to make it dynamic: The Switch Frame



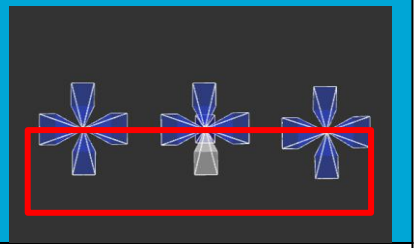
$$S = \begin{bmatrix} s & 0 & 0 \\ 0 & s & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad T = \begin{bmatrix} 1 & 0 & tx \\ 0 & 1 & ty \\ 0 & 0 & 1 \end{bmatrix}$$

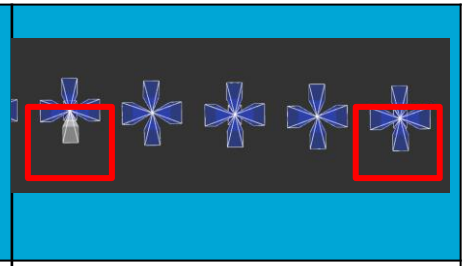
$$H_{final} = T \cdot S \cdot H \cdot S^{-1}$$

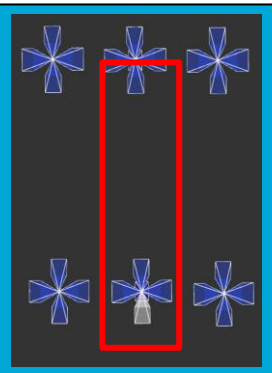

Preprocessing
Initial center image
Query: image belts in different directions
(sort by the distance to the center image)
Query: valid pairs in different directions
(considering both distance and number of matching tie-points)
Read neighbor images and homography matrix
Store in ImagePair table
Next image as the center
Mouse Move
In-between images
Interpolation
Adjust the homography matrix+
Warp the neighbor images to align with the center image
Get intersection Area
(in gray scale)
Optimal seam & Mask
Overlay and show
Calculate the unwarped coordinates of pixel for measurement
Image Morphing
Query: Coordinates of valid Tie-points on neighbor images
Resample the tie-points to get even distribution
Homography matrix (H)
Pre-calculated
Inverse homogrpahy matrix (H^{-1})

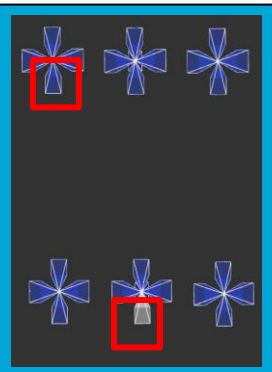
03

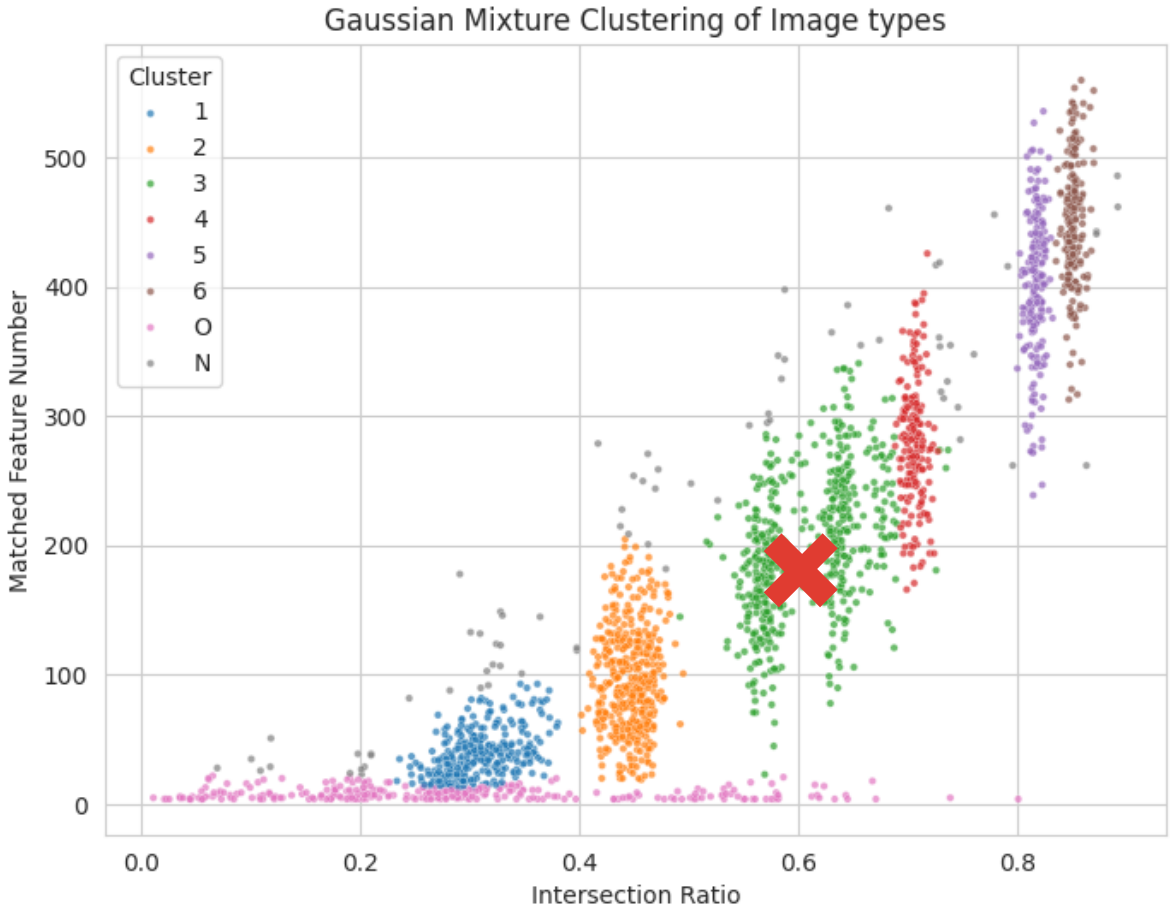
Results

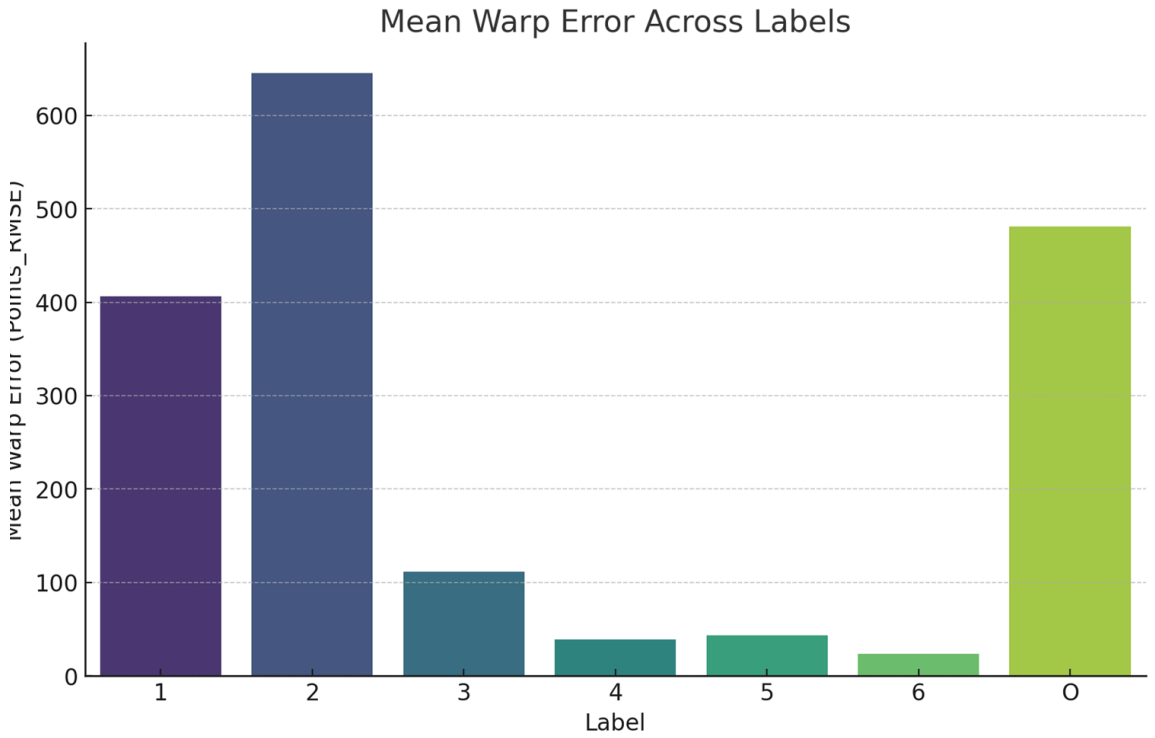
Spatial Relation	
Intersection rate	62.3%
RMSE	15.82

Spatial Relation	
Intersection rate	19.1%
RMSE	63.32

Spatial Relation	
Intersection rate	50.9%
RMSE	26.28

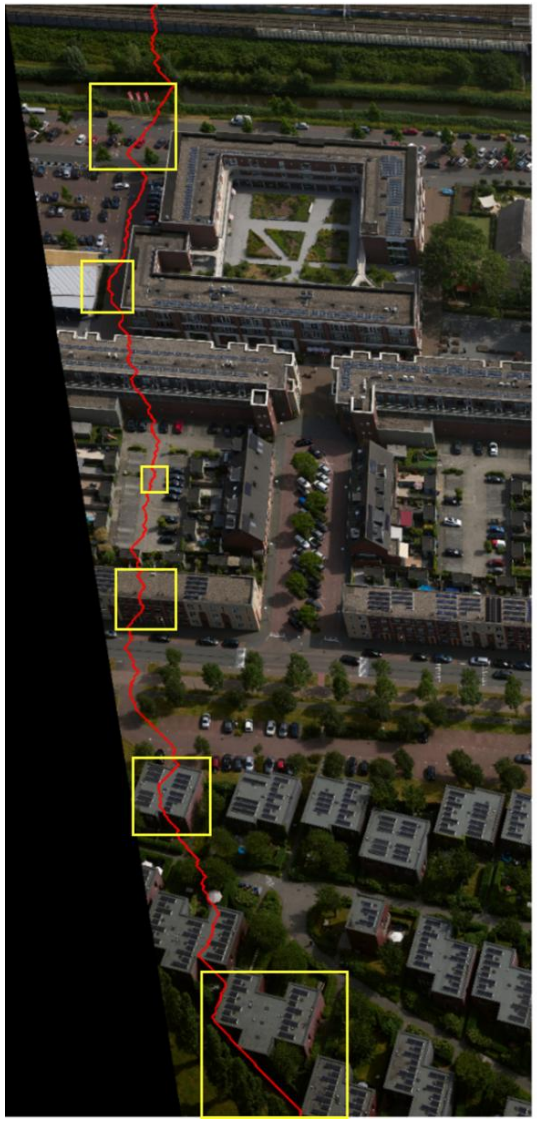
Spatial Relation	
Intersection rate	33.3%
RMSE	86.91

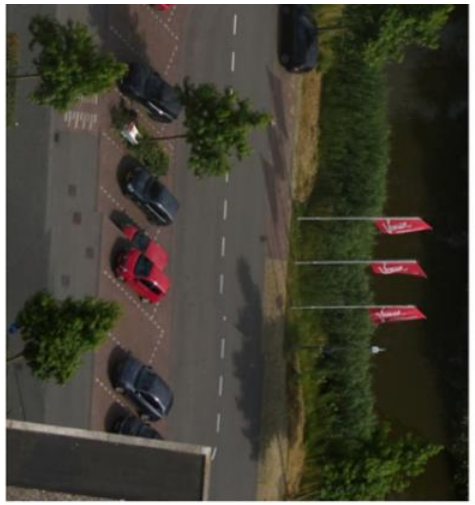

Gaussian Mixture Clustering of Image types
Cluster
1
2
3
4
5
6
O
N
Matched Feature Number
Intersection Ratio
0
100
200
300
400
500
0.0
0.2
0.4
0.6
0.8

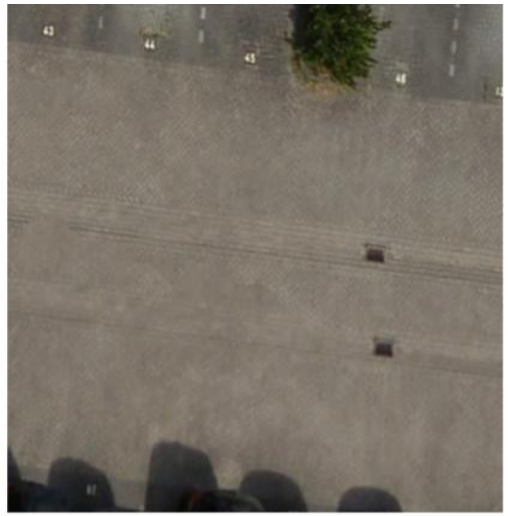

Mean Warp Error Across Labels
Label
0
100
200
300
400
500
600
1
2
3
4
5
6
O

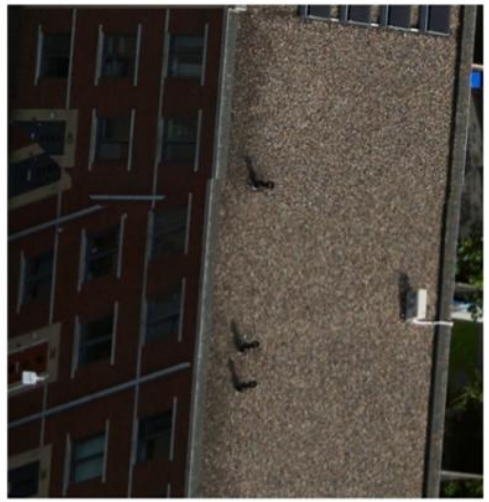
Without Optimal Seam

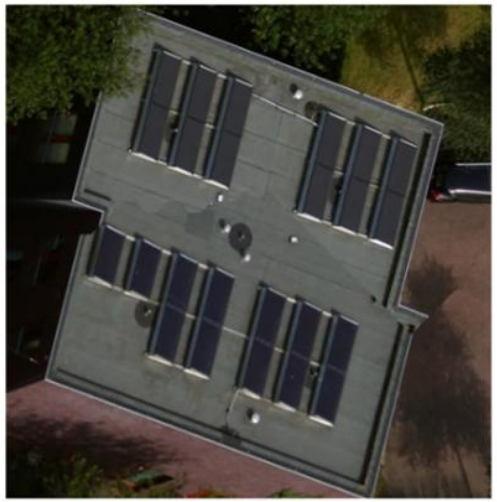
With Optimal Seam





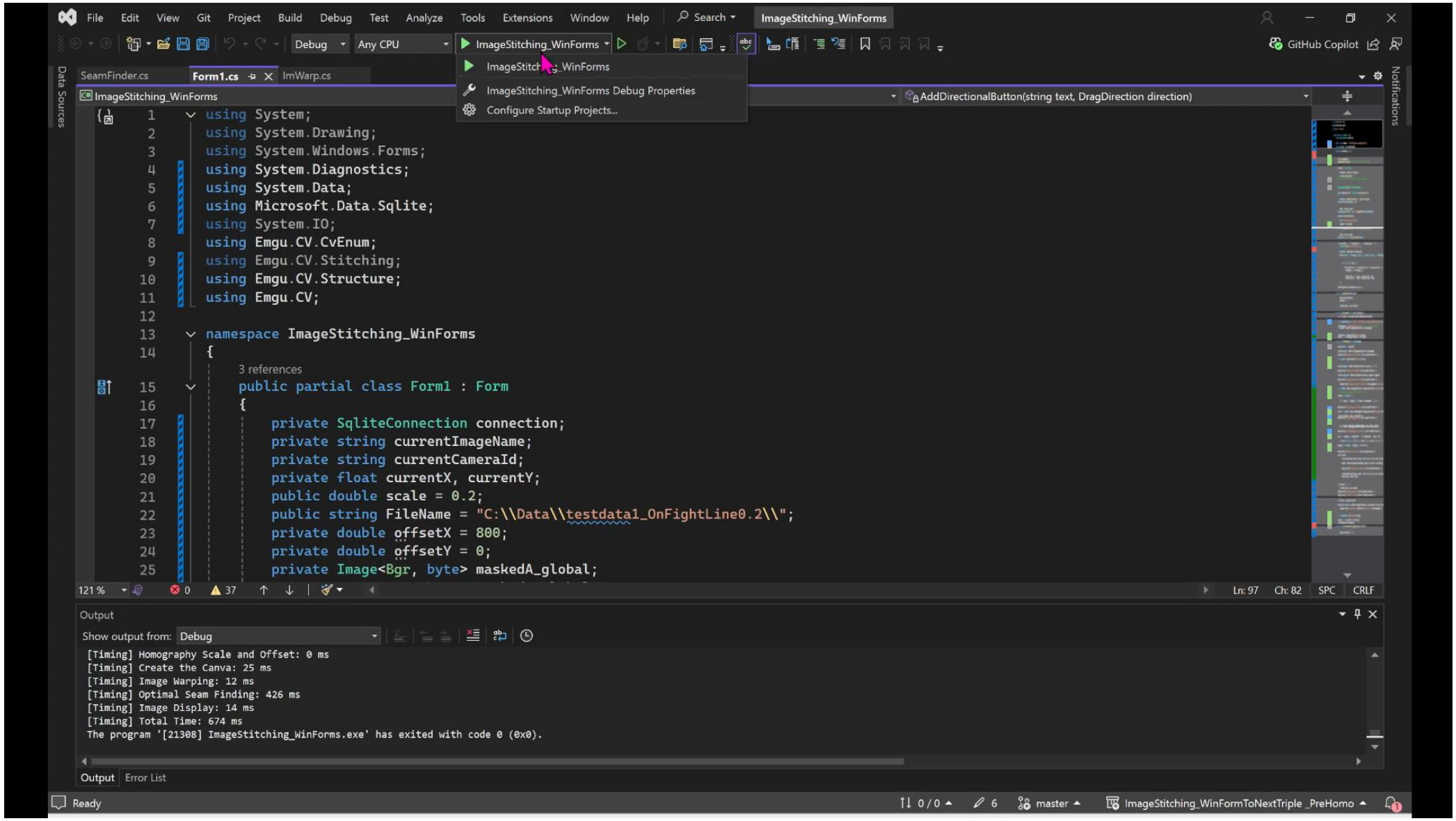




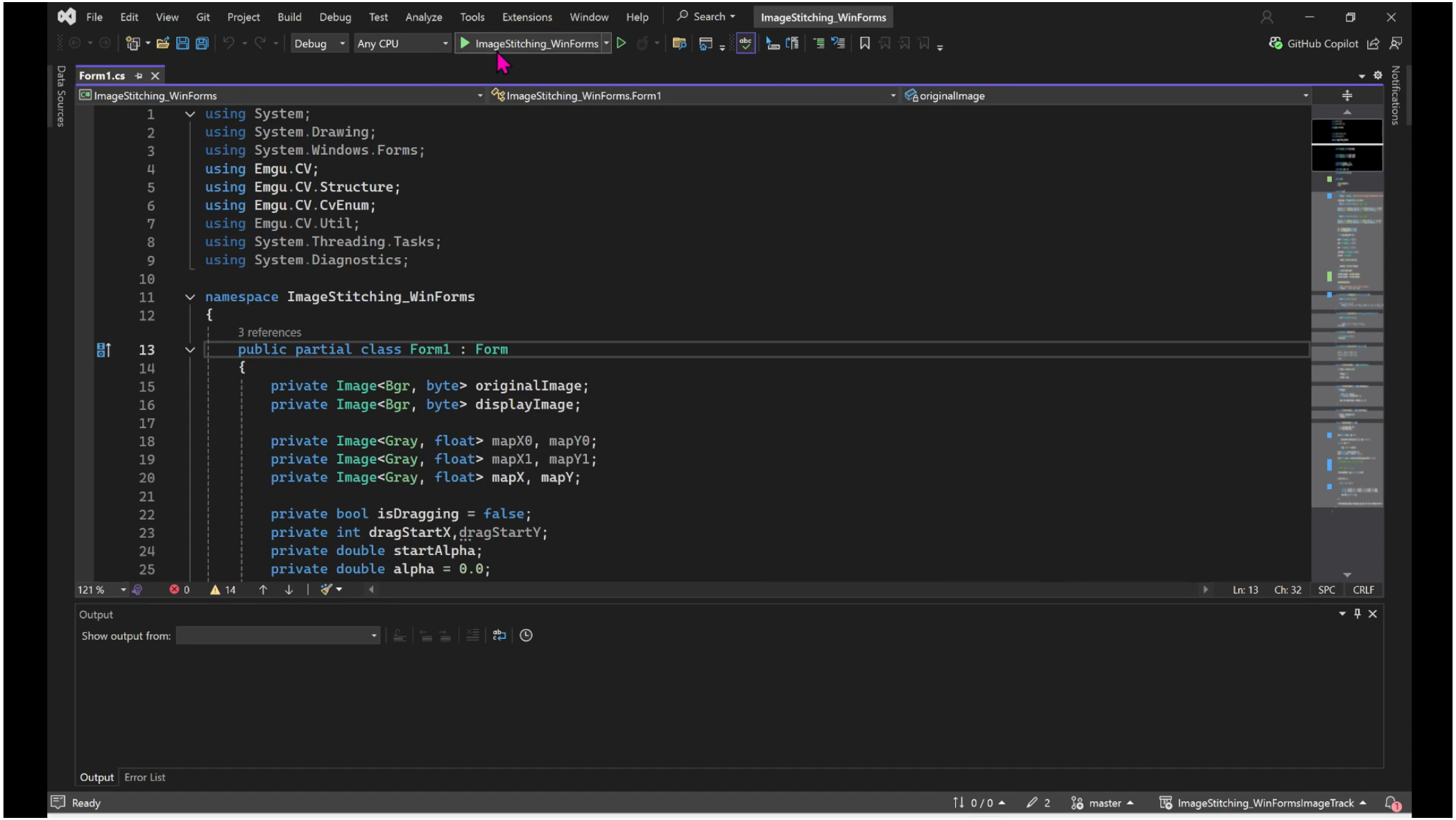


Stage	Original	Optimized
Create Canva	16.00	15.00
DB Read Center Image Information	0.00	0.00
Image Load and Resize	6673.75	74.25
DB Find Neighbors	0.00	0.00
DB Read Image Pairs	115.50	106.75
Homography Calculation	554.75	0.00
Homography Scale and Offset	1.25	0.00
Image Warping	12.00	12.00
Optimal Seam Finding	802.25	382.00
Image Display	471.00	8.50
Total Time	8630.5	585.50

Table 6.6.: Comparison of Average Running Times (Units: ms)

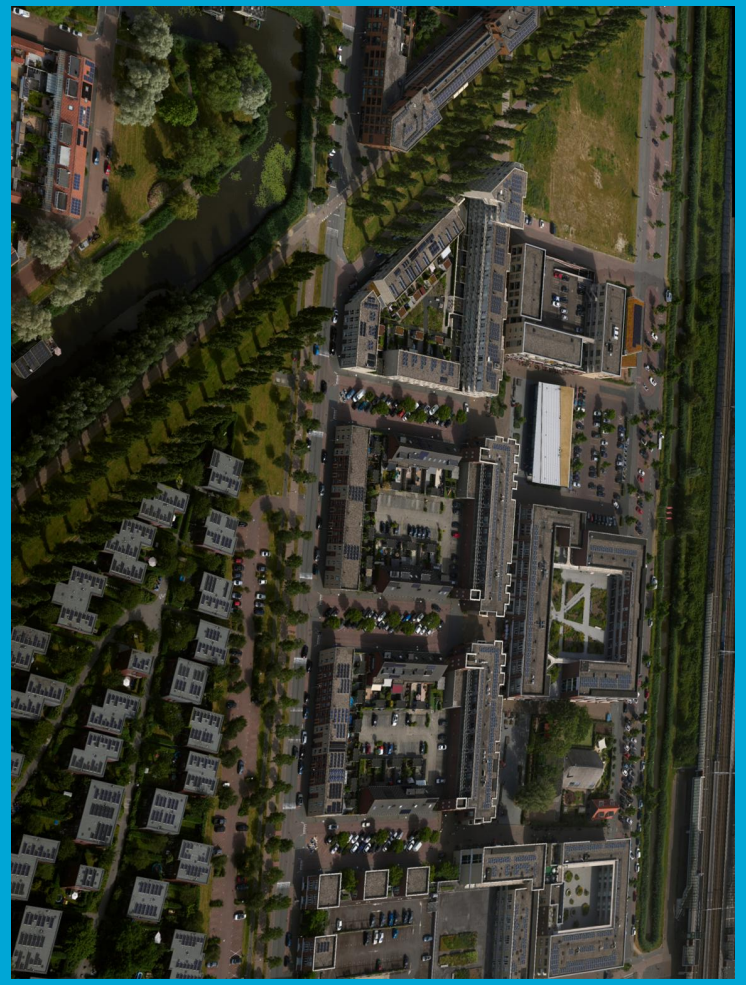


Demo- Dynamic Switch



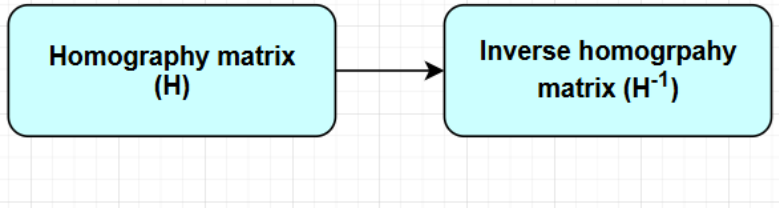
Demo- Image Morphing

Seamless



Smooth

Measurable



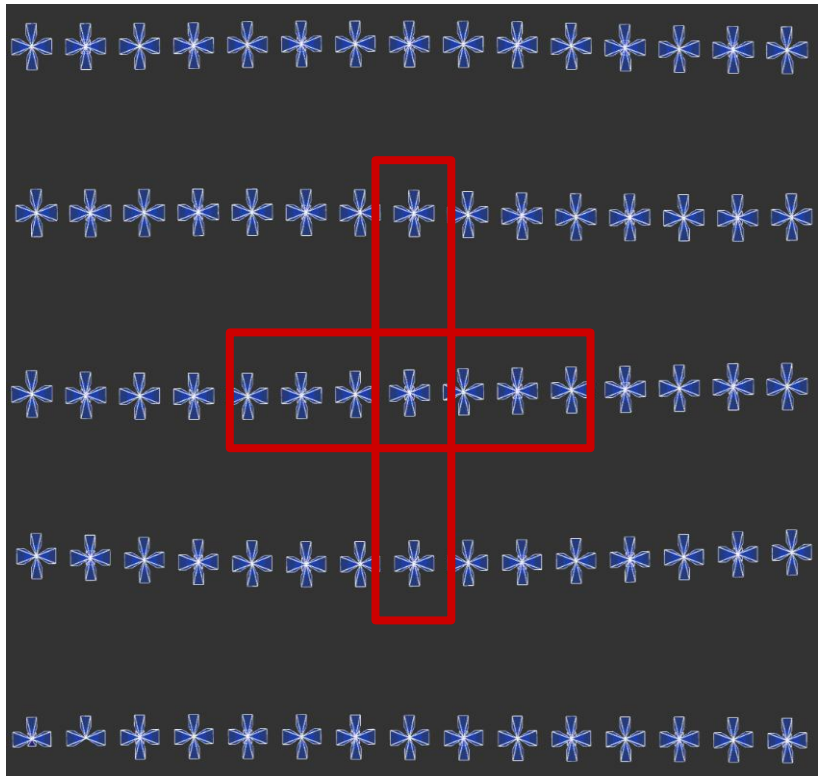
Transformed_x	Transformed_y	Original_x	Original_y	Type	Reversed_x	Reversed_y
1003	6930	1037	902	RoofCorner	1036.92	902.11
7661	7004	7657	1999	Solar Panel	7656.89	1998.87
12487	6142	12449	1886	RoofCorner	12449.01	1885.74
571	16422	635	10167	RoofCorner	634.76	10166.84
6088	12636	6078	7303	RoofCorner	6077.68	7303.28
6037	13306	6025	7951	RoofCorner	6025.31	7950.74
5946	14132	5933	8743	Window	5933.14	8743.43
7473	6985	7470	1952	Solar Panel	7470.39	1951.21
7424	7071	7420	2029	Solar Panel	7421.36	2028.85
7612	7092	7608	2079	Solar Panel	7607.84	2078.48
6516	12604	6501	7337	RoofCorner	6500.23	7336.63
5961	13936	5948	8554	Window	5948.50	8554.47
5864	14131	5852	8729	Window	5852.33	8730.11
12195	11955	12102	7560	RoofCorner	12102.77	7559.35
6468	13267	6450	7977	RoofCorner	6450.55	7977.63
5877	13939	5867	8546	Window	5865.69	8544.75
8448	13855	8398	8849	Flowerbed	8398.95	8849.65
9184	13769	9123	8877	Flowerbed	9123.98	8876.48
9166	14044	9104	9141	Flowerbed	9104.50	9141.76
8432	14133	8380	9119	Flowerbed	8381.64	9118.19

TU Delft

Goals achieved!

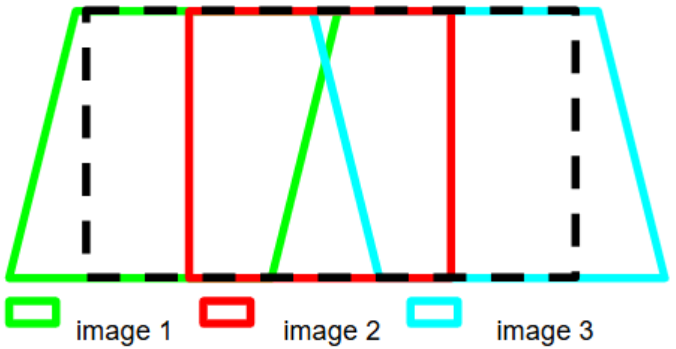
04

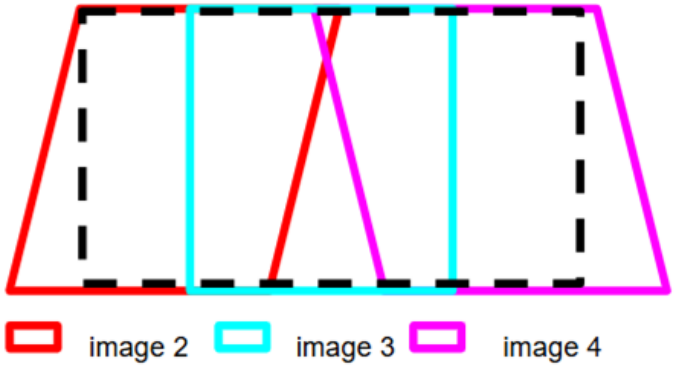
Limitation & Suggestions



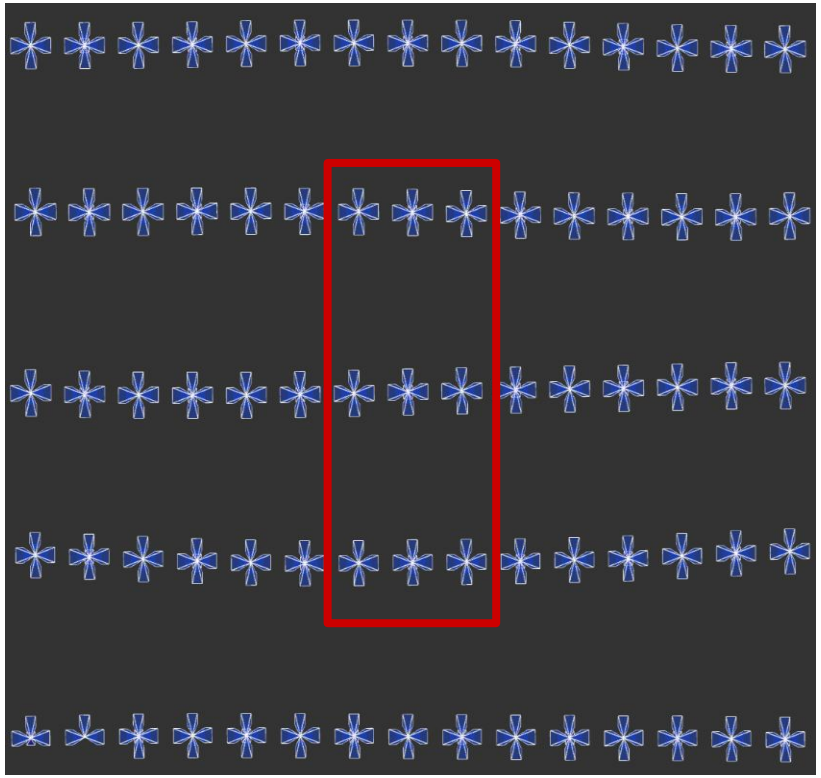
(adopted from Omnibase)

Limited Image Stitching



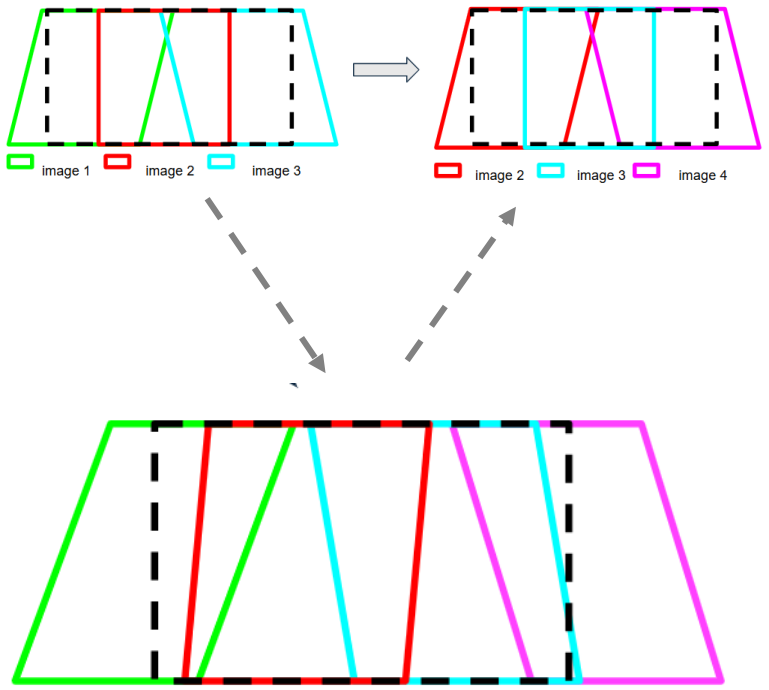


Hard Transition

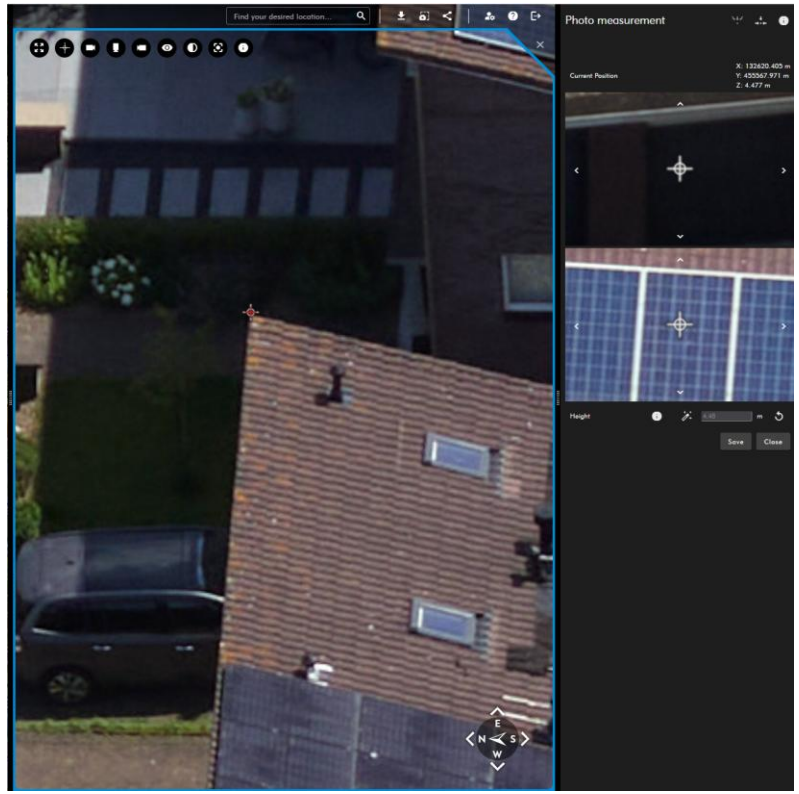


(adopted from Omnibase)

Multi-Image Stitching



Soft Transition



(adopted from Omnibase)

Integrate with Omnibase for Measurement

Thanks for your attention!

Seamless Oblique Image Mosaics for Aerial Visualization

Master of Geomatics | Xiaoluo Gong