Accurate Efficient Mosaicking for Wide Area Aerial Surveillance

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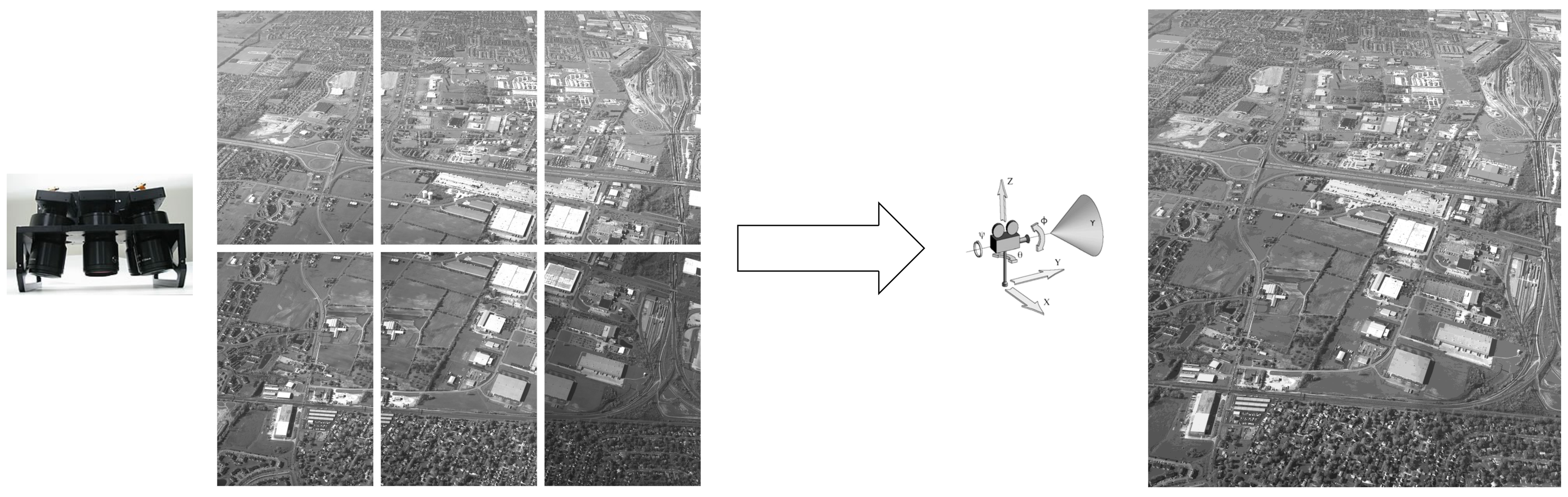
Problem



- Wide Area Aerial Surveillance (WAAS) imagery is captured by an array of sensors sharing an optical center
- It is desirable to generate a single image (mosaic) from the array
- Classic image deformation models (lens distortion) do not produce a seamless mosaic

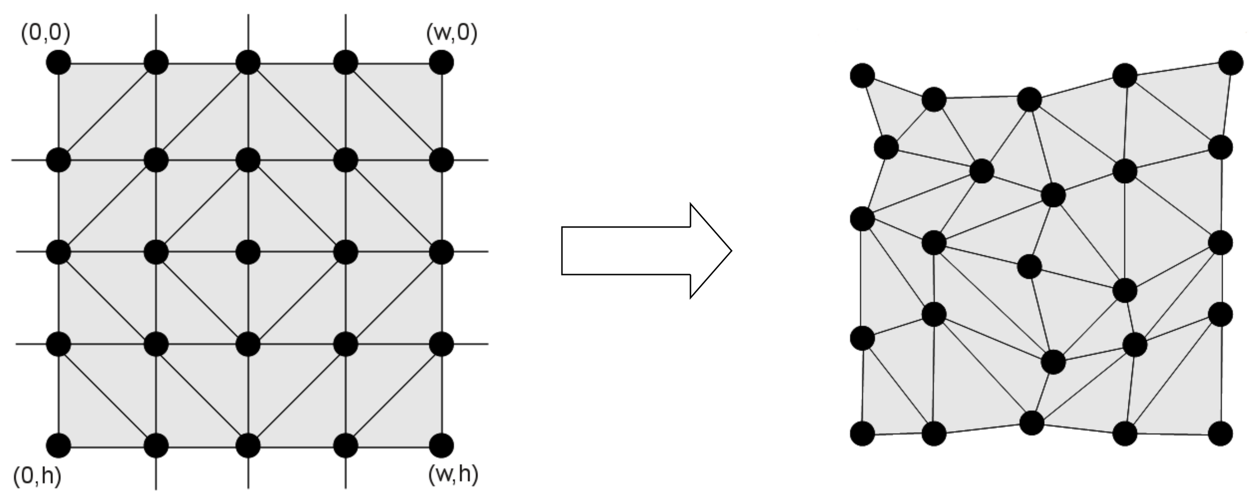
Strategy

$$\mathbf{p}' = H \cdot L(\mathbf{p};\, \theta)$$

- A homography model, H, registers two images captured by a rotating pinhole camera (**p** is a point in source image and **p'** is a point in destination image)
- Additional deformation, L, with parameters θ, is needed to account for distortions occurring in practice (lens, little parallax, …)

Piecewise Affine Model (PAM)

$$L(q) = \sum_{k=1}^{K} \delta(m(q)-k) A_k q$$



- Tessellate the image into K triangular regions as shown above. Each region has an associated affine transformation, A_k.
- The model is parameterized by the coordinates of each grid point after the deformation. A_k is estimated from three point correspondences.

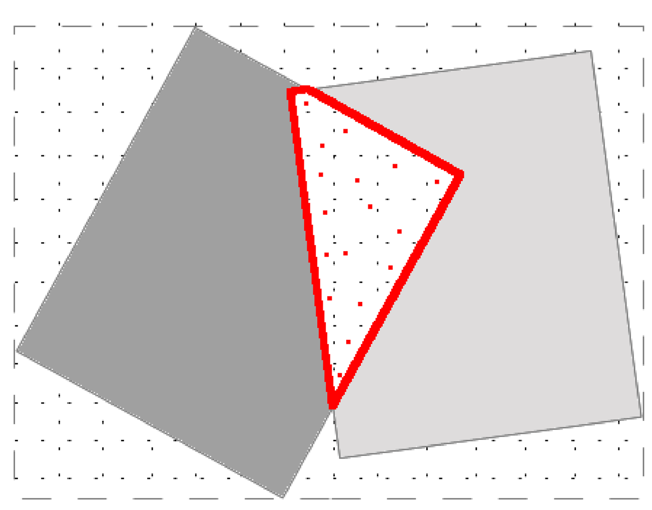
Estimating PAM

- Minimize the intensity variance of overlapping pixels

$$E(H_1,\cdots,H_l,\theta_1,\cdots,\theta_l) = \sum_p \frac{1}{O(p)} \sum_o^{O(p)} \left(I_o\left(L_o^{-1}\left(H_o^{-1} p\right)\right) - \mu(p)\right)^2$$

- Using all overlapping pixels in the optimization would be too slow
- Select spatially distributed pixels with high gradient

Very efficient, fast convergence
- Analytical Jacobian
- Only a fraction of overlapping pixels needed in the objective



Intensity Correction

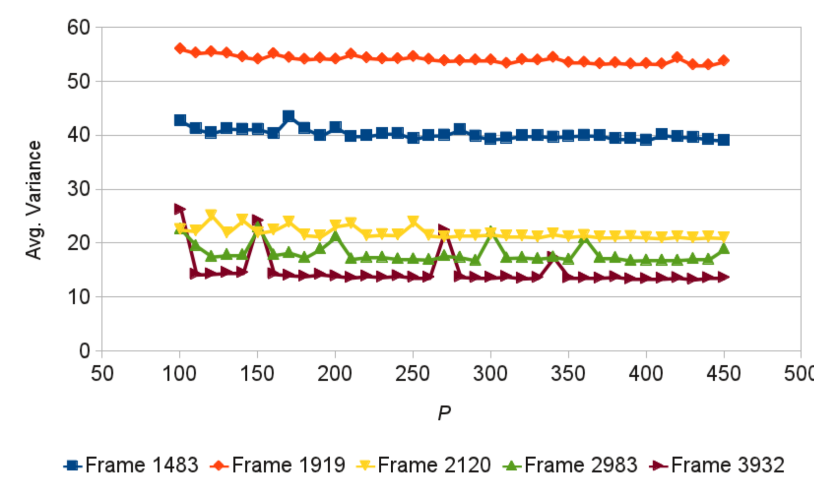
- Model the differences in intensity as differences in camera gain (scaling factor)
- Find pairwise gain corrections and use these as constraints in global optimization

Example
- Known corrections between images 0→1, 0→2, 1→3, …
- Solve for unknown image corrections g_0, g_1, g_2, g_3, g_4, g_5

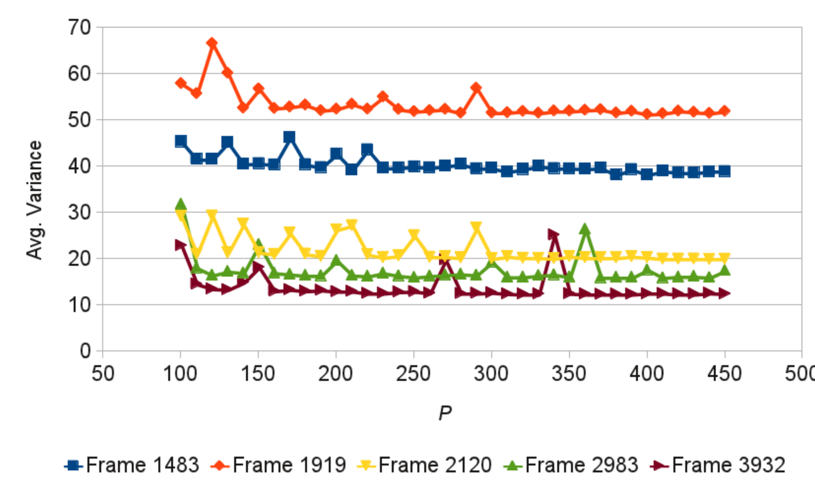
$$\begin{bmatrix} 1 & -g_{01} & 0 & 0 & 0 & 0 \\ 1 & 0 & -g_{02} & 0 & 0 & 0 \\ 0 & 1 & 0 & -g_{13} & 0 & 0 \\ 0 & 0 & 1 & -g_{23} & 0 & 0 \\ 0 & 0 & 1 & 0 & -g_{24} & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{bmatrix} \begin{bmatrix} g_0 \\ g_1 \\ g_2 \\ g_3 \\ g_4 \\ g_5 \end{bmatrix} = 0$$

PAM Parameters

- Model complexity, N (number of triangles = $2(2N)^2$)
- Sampling grid size, P (number of pixels used in optimization < P^2)



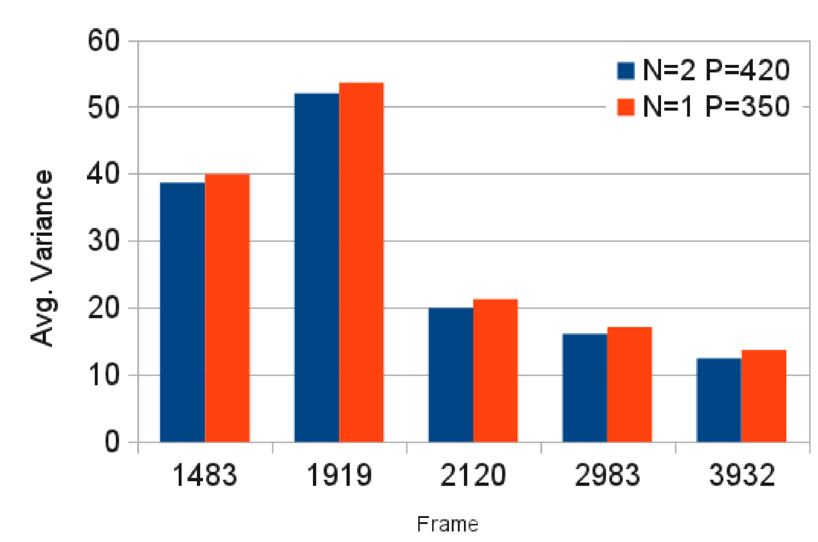
N=1



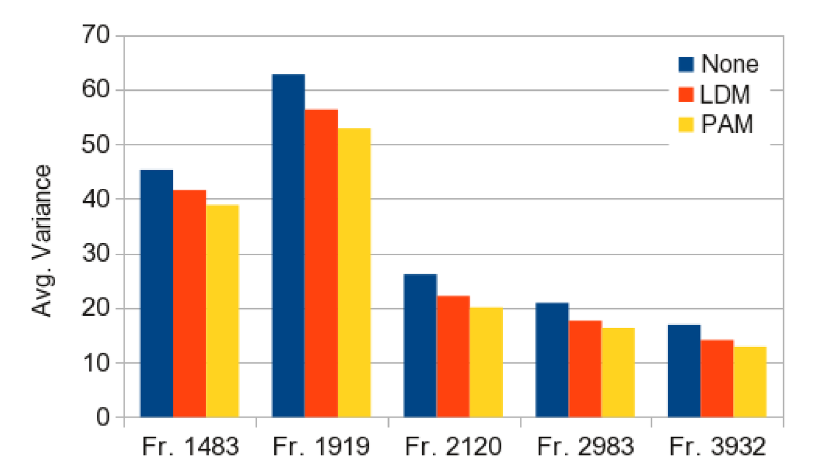
N=2

Results

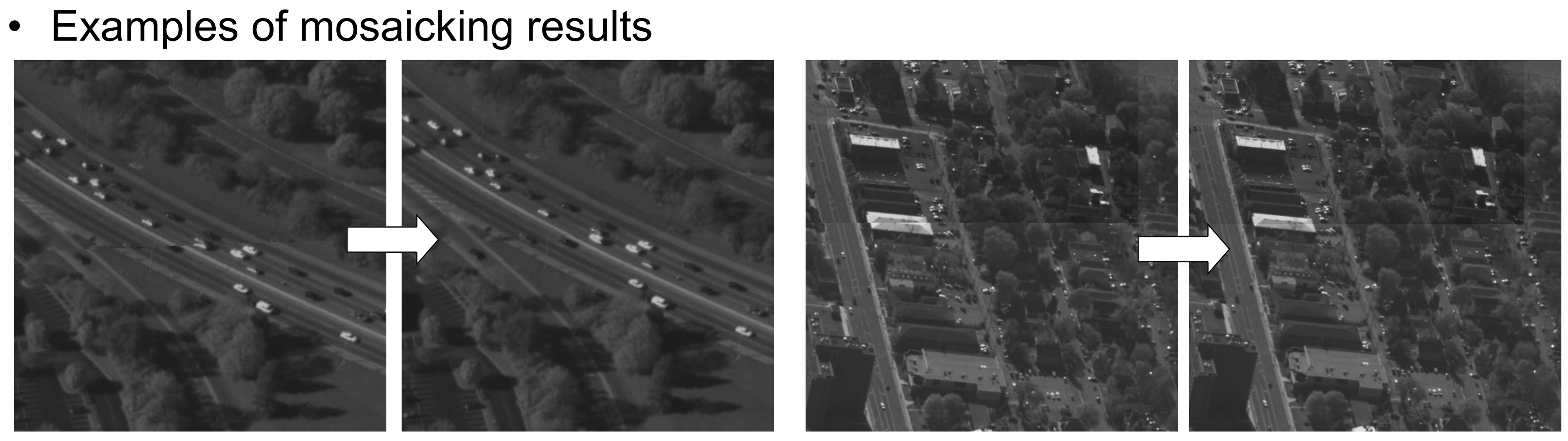
- Effect of PAM complexity on mosaicking accuracy



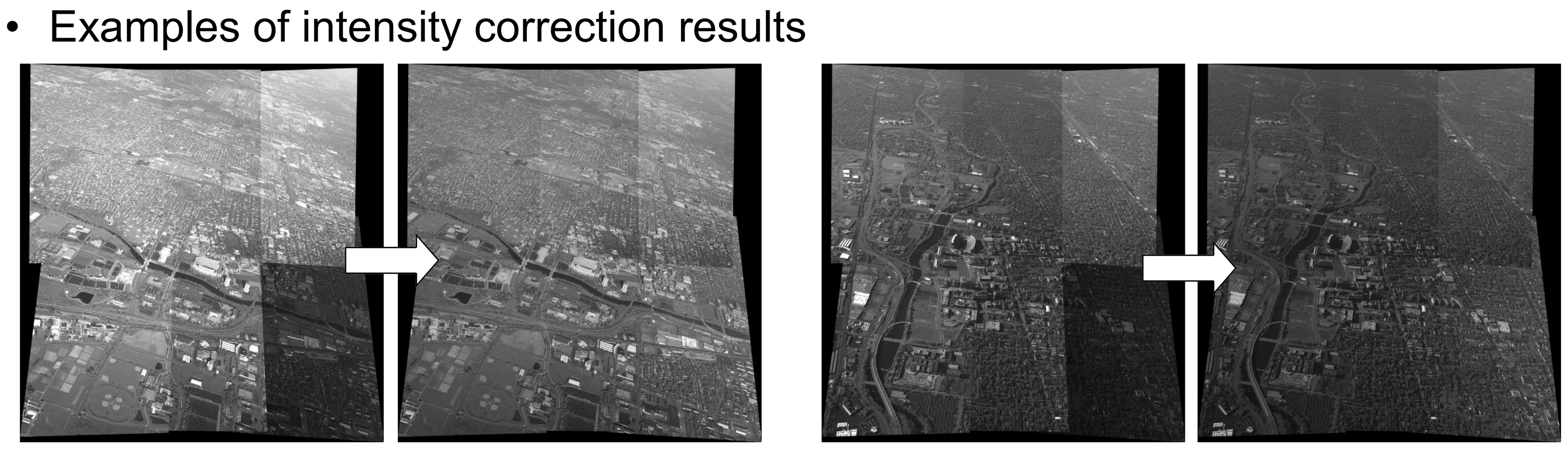
- Comparison of different deformation models



- Examples of mosaicking results



- Examples of intensity correction results



Conclusions and Future Work

- The proposed algorithm outperforms the standard lens distortion model while being very efficient (50 seconds to mosaic 6 WAAS images with N=2, P=420)
- Potential for real-time performance in the future with GPU implementation

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