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
\[ p' = H \cdot L(p, \theta) \]
- 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 \( \theta \), is needed to account for distortions occurring in practice (lens, little parallax, ...)

Piecewise Affine Model (PAM)
\[ L(p) = \sum_{k=1}^{K} \delta(p) - k \cdot L_k \]
- 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
  \[ E(H, \ldots, H, \theta, \ldots, \theta) = \sum \frac{1}{P(p)} \sum_{k} \delta(p, [H_k \cdot \theta]) \cdot \mu(p) \]
- 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\( \rightarrow \)1, 0\( \rightarrow \)2, 1\( \rightarrow \)3, ...
- Solve for unknown image corrections \( g_0, g_1, g_2, g_3, g_4, g_5 \)

\[
\begin{align*}
1 - K_{10} & 0 & 0 & 0 & 0 & g_1 \\
0 & 1 - K_{21} & 0 & 0 & 0 & g_2 \\
0 & 0 & 1 - K_{32} & 0 & 0 & g_3 \\
0 & 0 & 0 & 1 - K_{43} & 0 & g_4 \\
0 & 0 & 0 & 0 & 1 - K_{54} & g_5 \\
\end{align*}
\]
- \( K_{ij} = 0 \) for all corrections

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

Results
- Effect of PAM complexity on mosaicking accuracy
- Comparison of different deformation models

Examples of mosaicking 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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