Probabilistic Motion Estimation for Rolling Shutter Video Rectification from Visual and Inertial Measurements

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3/7/2012
Rotation estimation using IMUs

• Pure rotational model
• Related work
  – [Karpenko 2011] direct integral of gyro readings
  – [Hanning 2011] EKF-based: gyro as control inputs; accel. as measurements (assuming gravitational acceleration is the only source)
• Ours
  – More accurate: make use of visual measurements
  – Relative pose estimate
Camera model and Gyro readings

• Gyro has higher sampling frequency

• Each frame corresponds to a group of gyro readings
EKF-based Estimation

• Foundation of the method

$$u' \sim KR(t(u', i))R^T(t(u, j))K^{-1}u$$

$$R(t(u', i + 1))R^T(t(u, i)) = \prod_{n=k+1}^{k+4} \Delta R(\omega_n \Delta t_n)$$
EKF-based Estimation

- State vector: two groups of angular velocity
  \[
  x(i) = [\omega(i, 1), \ldots, \omega(i, N_i), \omega(i + 1, 1), \ldots, \omega(i + 1, N_{i+1})]^T
  \]

- Probabilistic model
Dynamic Motion Model

• “Group cloning”

\[
x(i) = \begin{bmatrix} x_{i,1} \\ x_{i,2} \end{bmatrix} = \begin{bmatrix} x_{i-1,2} \\ y_i \end{bmatrix} + \begin{bmatrix} 0 \\ w_i \end{bmatrix}
\]

• Linear model

\[
A_i = \frac{\partial f}{\partial x} \bigg|_{x_{i-1}} = \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix},
W_i = \frac{\partial f}{\partial w} \bigg|_{w_i} = \begin{bmatrix} 0 \\ I \end{bmatrix}
\]
Measurement Model

- Use only feature points in frame i as the measurements; their matching points in frame (i-1) are used as known parameters.

\[ u_{i, j} = p \left( K \Delta R K^{-1} \left[ u_{i-1, j} + v_{i,j,1} \right] \right) + v_{i,j,2} \]

\[ z_i = \begin{bmatrix} u_{i,1} \\ u_{i,2} \\ \vdots \\ u_{i,M} \end{bmatrix} = \begin{bmatrix} h_1(x_i, u_{i-1,1}, v_{i,1}) \\ h_2(x_i, u_{i-1,2}, v_{i,2}) \\ \vdots \\ h_M(x_i, u_{i-1,M}, v_{i,M}) \end{bmatrix} \]
Avg re-projection error / point
Accuracy evaluation

- Simple zero-converging test
Rolling Shutter Effect Rectification
Numerical Comparison

• No ground truth $\rightarrow$ self-checking method
• Vanishing point

<table>
<thead>
<tr>
<th>Rectification method</th>
<th>Video #1</th>
<th>Video #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>No rectification (original)</td>
<td>3.500</td>
<td>2.800</td>
</tr>
<tr>
<td>Orientation estimated by [3]</td>
<td>1.820</td>
<td>2.150</td>
</tr>
<tr>
<td>Orientation estimated by proposed method</td>
<td>1.180</td>
<td>0.800</td>
</tr>
</tbody>
</table>
Future work

• User study for quality assessment
• Optimal causal low-pass filter
  (stability vs. viewable size)
• Fast forward warping method
• Ready for application
• Better motion model
  (fast linear motion; large scene depth)
• Simultaneous Deblurring