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

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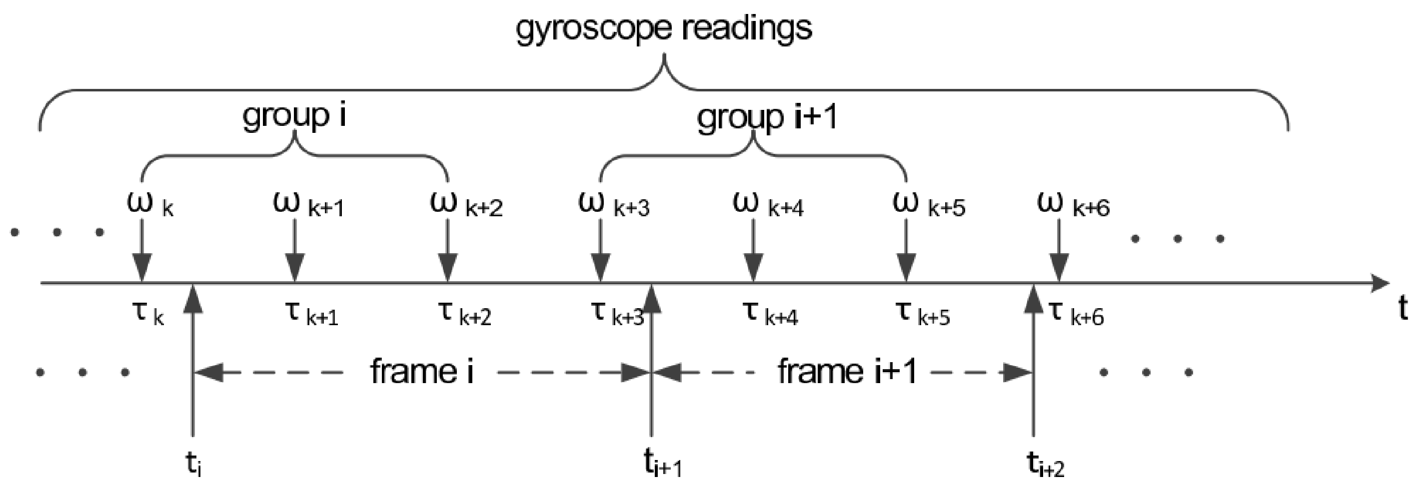
Rotation estimation using IMUs

- 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

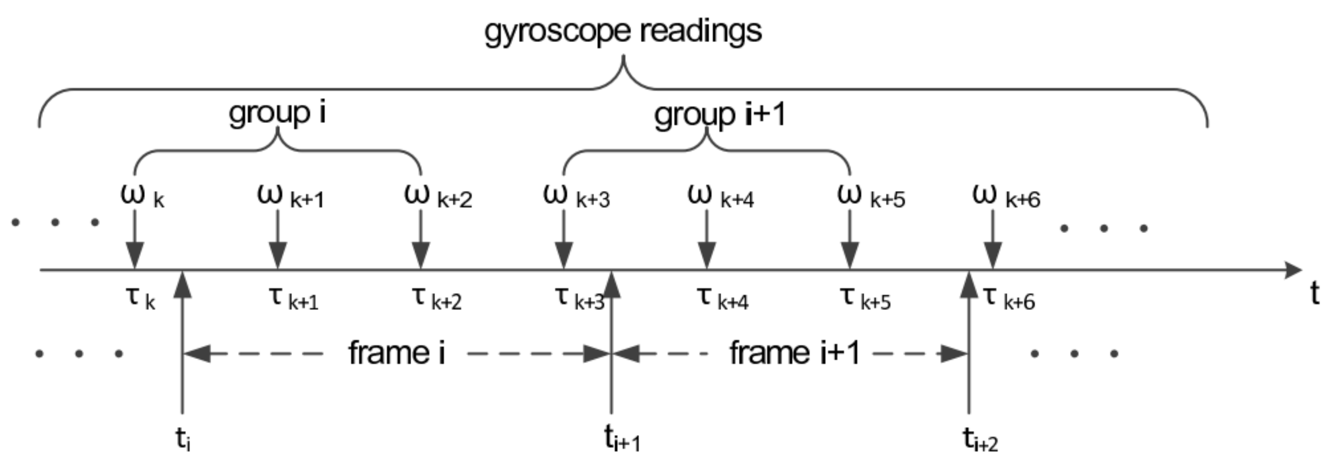


- Each frame corresponds to a group of gyro readings

EKF-based Estimation

- Foundation of the method

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



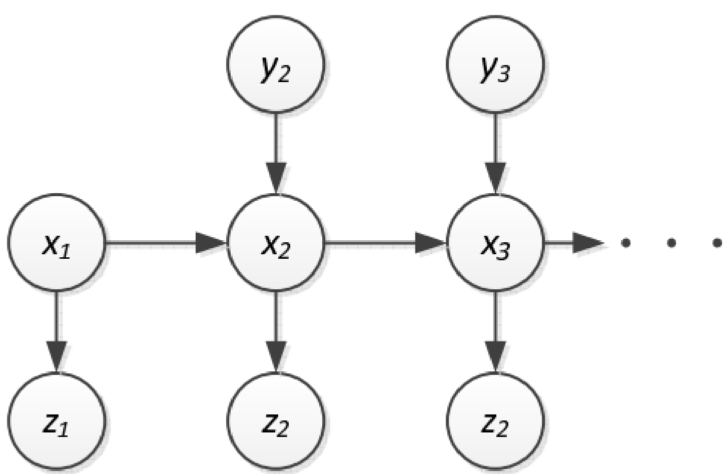
$$\mathbf{R}(t(\mathbf{u}', i+1))\mathbf{R}^T(t(\mathbf{u}, i)) = \prod_{n=k+1}^{k+4} \Delta\mathbf{R}(\omega_n \Delta t_n)$$

EKF-based Estimation

- State vector: two groups of angular velocity

$$\mathbf{x}(i) = [\omega(i,1), \ldots, \omega(i,N_i), \omega(i+1,1), \ldots, \omega(i+1,N_{i+1})]^T$$

- Probabilistic model



Dynamic Motion Model

- "Group cloning"

$$\mathbf{x}(i) = \begin{bmatrix} \mathbf{x}_{i,1} \\ \mathbf{x}_{i,2} \end{bmatrix} = \begin{bmatrix} \mathbf{x}_{i-1,2} \\ \mathbf{y}_i \end{bmatrix} + \begin{bmatrix} \mathbf{0} \\ \mathbf{w}_i \end{bmatrix}$$

- Linear model

$$A_i = \left.\frac{\partial f}{\partial \mathbf{x}}\right|_{\mathbf{x}_{i-1}} = \begin{bmatrix} \mathbf{0} & I \\ \mathbf{0} & \mathbf{0} \end{bmatrix}, W_i = \left.\frac{\partial f}{\partial \mathbf{w}}\right|_{\mathbf{w}_i} = \begin{bmatrix} \mathbf{0} \\ I \end{bmatrix}$$

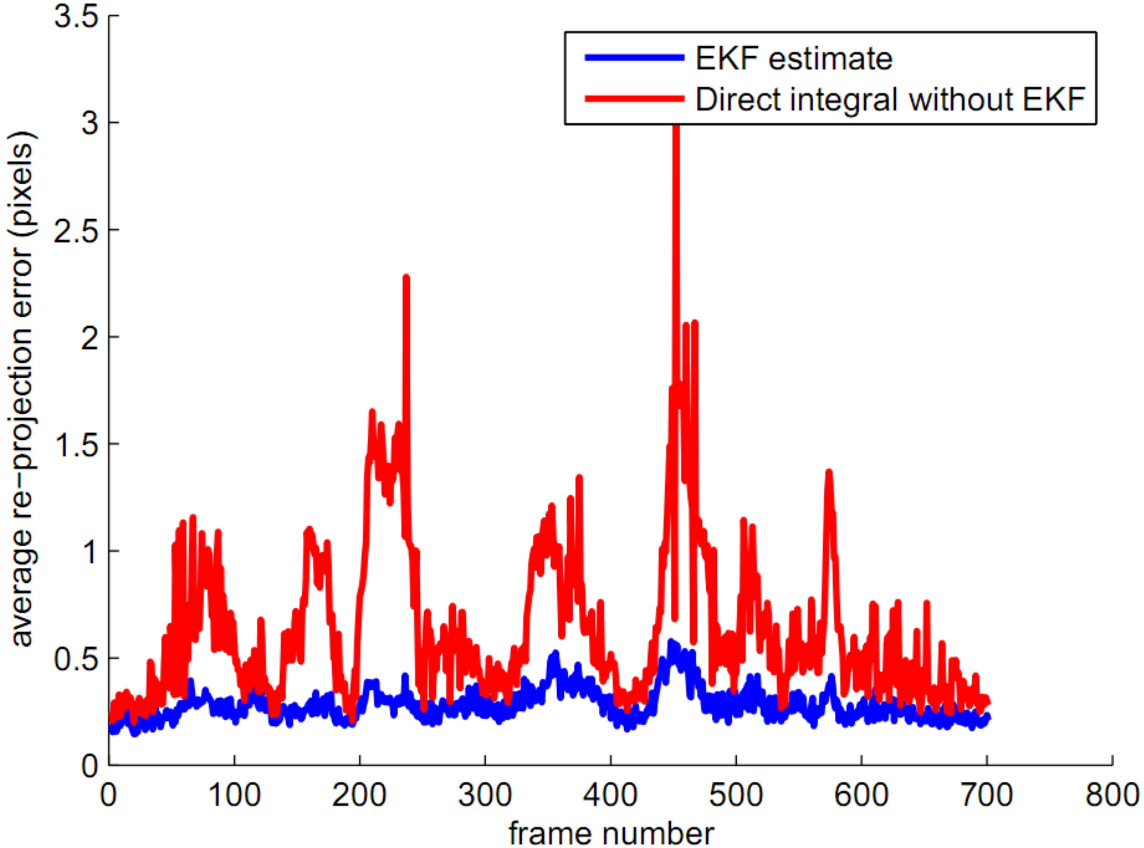
Measurement Model

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

$$\mathbf{u}_{i,j} = p\left(K\Delta R K^{-1}\begin{bmatrix} \mathbf{u}_{i-1,j} + \mathbf{v}_{i,j,1} \\ 1 \end{bmatrix}\right) + \mathbf{v}_{i,j,2}$$

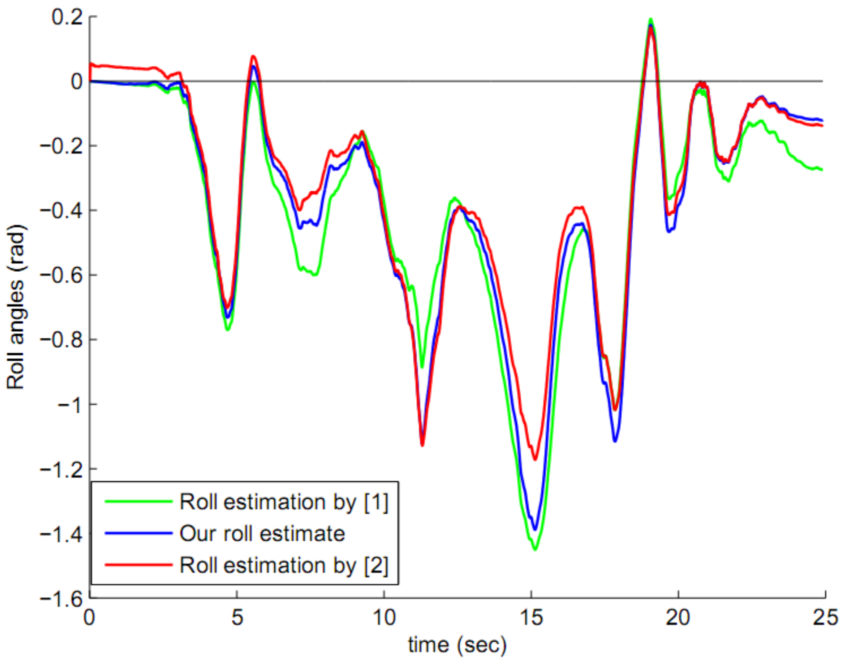
$$\mathbf{z}_i = \begin{bmatrix} \mathbf{u}_{i,1} \\ \mathbf{u}_{i,2} \\ \vdots \\ \mathbf{u}_{i,M} \end{bmatrix} = \begin{bmatrix} h_1(\mathbf{x}_i, \mathbf{u}_{i-1,1}, \mathbf{v}_{i,1}) \\ h_2(\mathbf{x}_i, \mathbf{u}_{i-1,2}, \mathbf{v}_{i,2}) \\ \vdots \\ h_M(\mathbf{x}_i, \mathbf{u}_{i-1,M}, \mathbf{v}_{i,M}) \end{bmatrix}$$

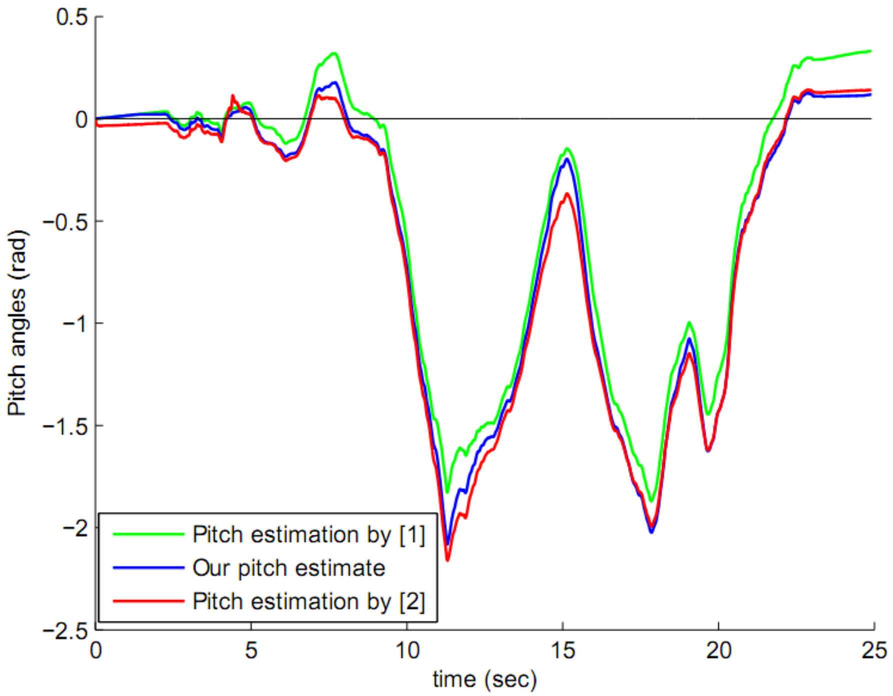
Avg re-projection error / point



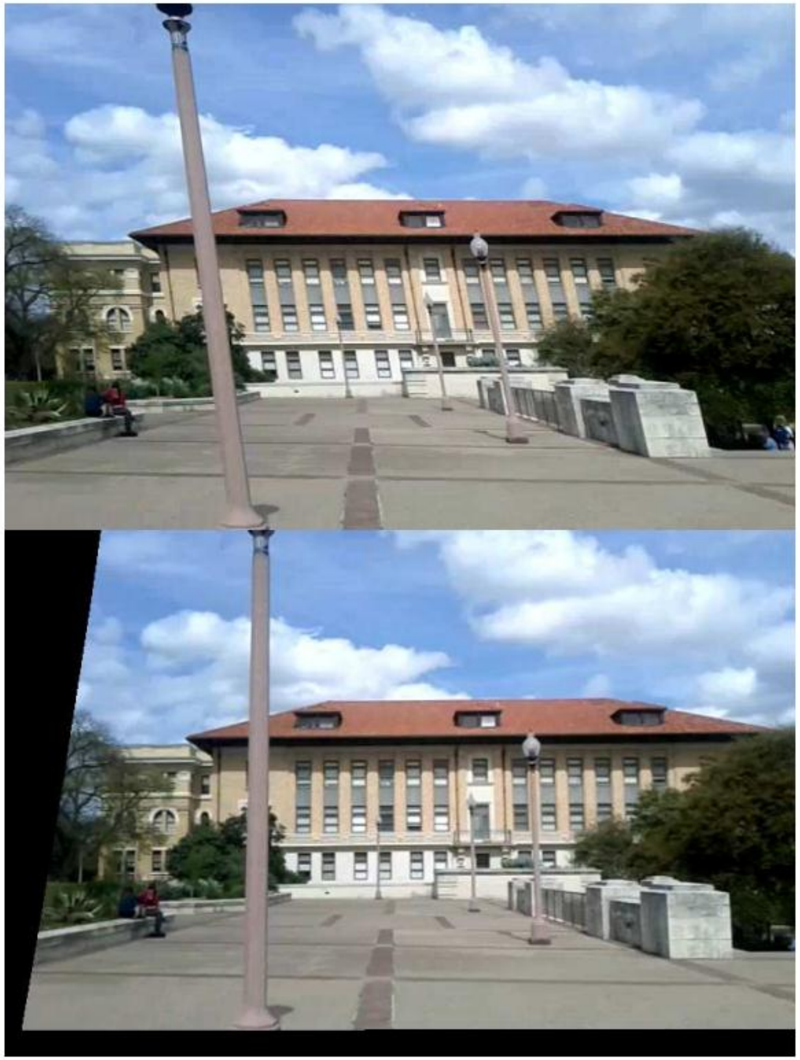
Accuracy evaluation

- Simple zero-converging test





Rolling Shutter Effect Rectification



Numerical Comparison

- No ground truth → self-checking method
- Vanishing point

AVERAGE EUCLIDEAN DISTANCE FROM THE LINES TO THE VANISHING POINT (IN PIXEL)

Rectification method	**Video #1**	**Video #2**
No rectification (original)	3.500	2.800
Orientation estimated by [3]	1.820	2.150
Orientation estimated by [4]	1.628	1.387
Orientation estimated by proposed method	1.180	0.800

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