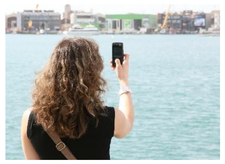
Online Calibration and Synchronization for Cellphone Camera and Gyroscope

Chao Jia and Brian L. Evans

1. Motivation

- Widely Use of Cellphone Cameras



Video Recording

Augmented Reality

Navigation

Camera Motion Estimation needed

- What makes motion estimation difficult?

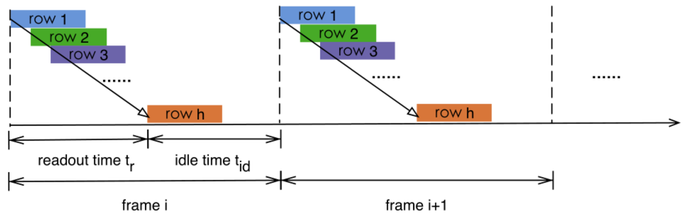
Motion changes very fast

CMOS sensor brings rolling shutter distortion

- Gyro-aided approach
  - ✓ High sampling rate; Robust to lighting condition
  - ✓ Sensor-calibration needed
- What makes a good camera-gyro calibration method
  - ✓ Online (better to be real-time)
  - ✓ Simple (translation & scene structure free)
  - ✓ Robust (works under arbitrary motion)

2. Parameters to Estimate

- Rows are captured sequentially in rolling shutter cameras

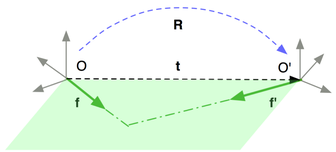


Intrinsic parameters f, c_x, c_y
RS readout time t_r

bias $\mathbf{b}_g$

relative orientation $\mathbf{q}_c$
delay (use gyro as reference) t_d

3. Coplanarity Constraint (translation free)



Epipolar constraint

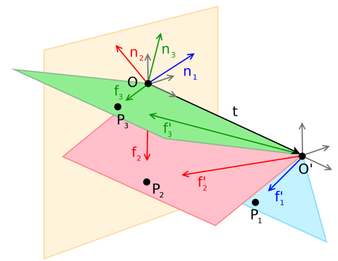
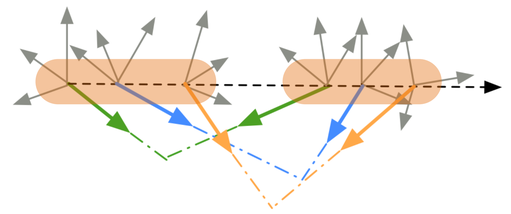


Image from [Kneip ECCV 2012]

Assume translation direction is constant



Pick any reference time

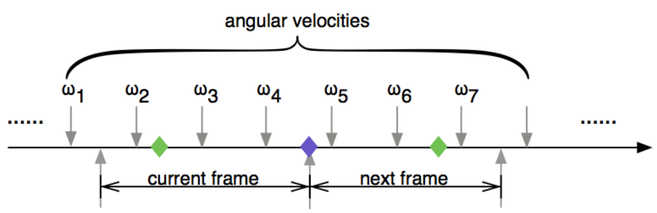
Coplanarity constraint of global shutter camera

$$\det[(\mathbf{R}_1\mathbf{f}_1 \times \mathbf{R}'_1\mathbf{f}'_1)|(\mathbf{R}_2\mathbf{f}_2 \times \mathbf{R}'_2\mathbf{f}'_2)|(\mathbf{R}_3\mathbf{f}_3 \times \mathbf{R}'_3\mathbf{f}'_3)] = 0$$

Coplanarity constraint of rolling shutter camera

4. EKF-based Calibration & Synchronization

- Relate Gyro and Camera



$$\mathbf{R}_i = \prod_{n=1}^{M} \exp([\boldsymbol{\omega}_n \Delta t_n^i]_\times),$$

t_r, t_d — $\mathbf{b}_g$ — $f, c_x, c_y, \mathbf{q}_c$

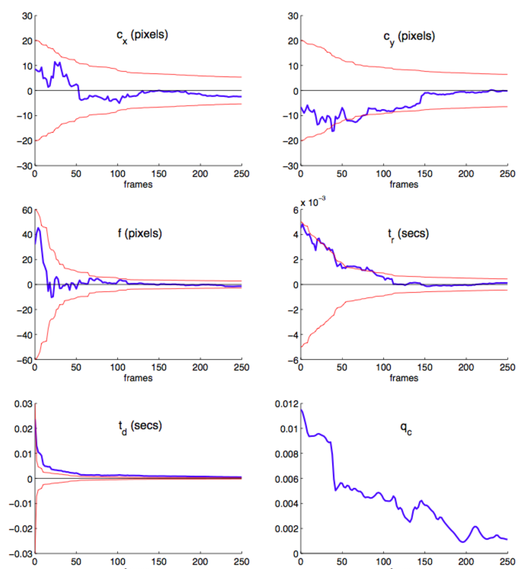
$$\det[(\mathbf{R}_1\mathbf{f}_1 \times \mathbf{R}'_1\mathbf{f}'_1)|(\mathbf{R}_2\mathbf{f}_2 \times \mathbf{R}'_2\mathbf{f}'_2)|(\mathbf{R}_3\mathbf{f}_3 \times \mathbf{R}'_3\mathbf{f}'_3)] = 0$$

Coplanarity constraint of rolling shutter camera

- Coplanarity constraints are used as implicit measurements.
- Update every other frame. (features are only used once)

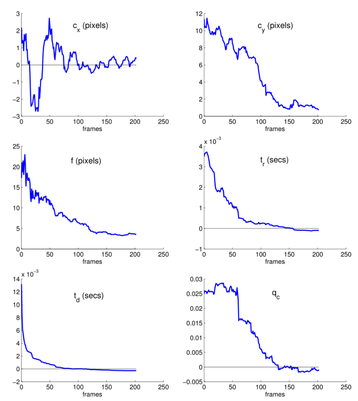
5. Experimental Results

- Monte Carlo Simulation
  - ✓ Random Motion & 3D features
  - ✓ Artificial noisy measurements

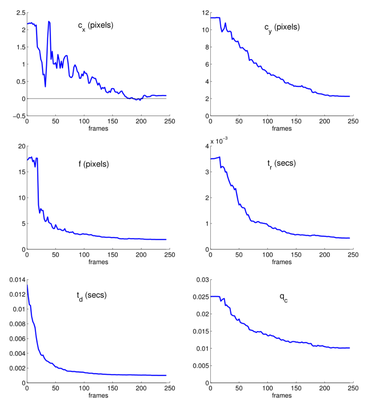


Estimation error over time in one trial

- Cellphone experiments (Google Nexus S phone)



Estimation error over the running sequence



Estimation error over the panning sequence

RMS error		
	before calibration	after calibration
f (pixels)	21.2822	2.3843
c_x (pixels)	6.8470	1.6820
c_y (pixels)	3.2166	1.6083
t_r (s)	0.0013	0.0002
t_d (s)	0.0121	0.0004
$\mathbf{q}_c$	0.0103	0.0040

RMS error of 50 Monte Carlo simulation trials

Running sequence

Panning sequence

Research is supported in part by a gift from Texas Instruments in Dallas, Texas.

Web page for the project is http://users.ece.utexas.edu/~bevans/projects/dsc/index.html