Change Detection in the Presence of Motion Blur and Rolling Shutter Effect

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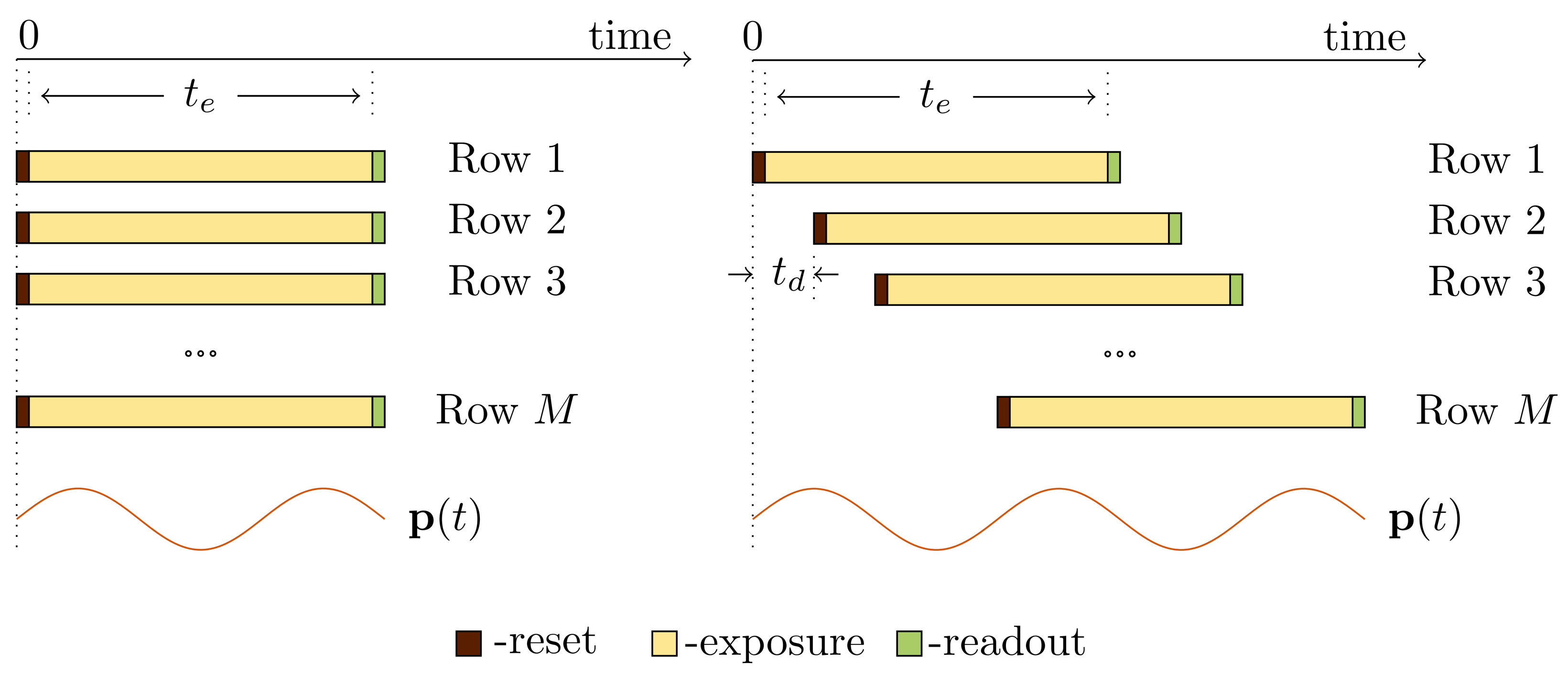
1 Introduction

- CMOS sensors are prevalent nowadays, especially in mobile phones, due to their low cost and power consumption
- Sequential exposure of rows in CMOS sensors causes both motion blur (MB) and rolling shutter (RS) effect
- Change detection in such images is a challenging task
- A joint framework is proposed to register a reference image and a distorted image, and to also simultaneously detect occlusions
- Assumption: The reference image is clean and free from artifacts

2 Motion Blur in Rolling Shutter Cameras

- Each row in a rolling-shutter camera experiences different camera motion during its own unique exposure time
- This is unlike global shutter (GS) cameras, where all the pixels are exposed during the same period
- Induced motion blur is thus different



(a) Global shutter (b) Rolling shutter

- Due to the camera motion trajectory $\mathbf{p}(t)$, every row of the observation $\mathbf{g}$ is equal to the corresponding row in the weighted average of warps of $\mathbf{f}$

$$\mathbf{g}^{(i)} = \frac{1}{t_e}\int_{(i-1)t_d}^{(i-1)t_d+t_e} \mathbf{f}^{(i)}_{\mathbf{p}(t)}\, dt, \text{ for } i = 1 \text{ to } M \quad (1)$$

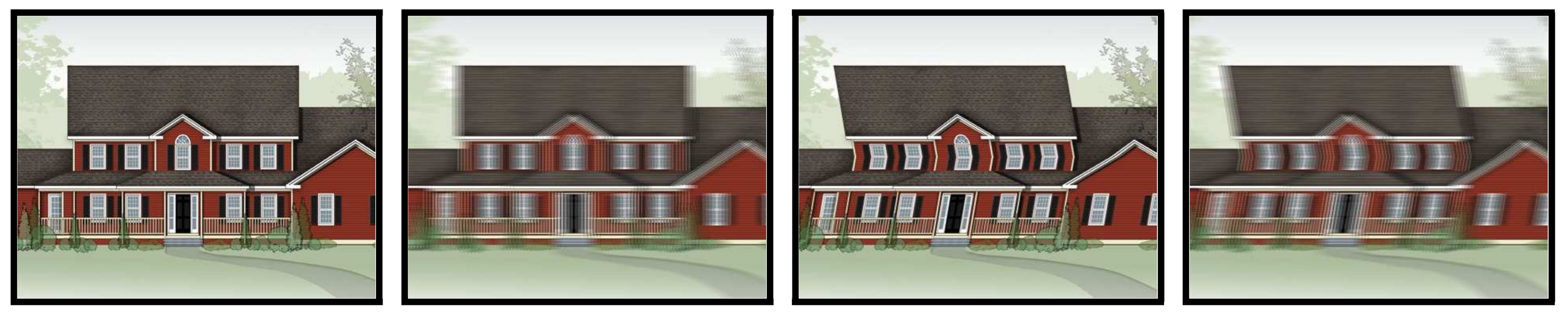
$\mathbf{f}^{(i)}_{\mathbf{p}(t)}$ represents the ith row of the warped version of $\mathbf{f}$ due to the camera pose $\mathbf{p}(t)$

- Discretisation with respect to a camera pose space $\mathcal{S}^{(i)} = \{\boldsymbol{\tau}_k\}$

$$\mathbf{g}^{(i)} = \sum_{\boldsymbol{\tau}_k \in \mathcal{S}} \omega^{(i)}_{\boldsymbol{\tau}_k} \mathbf{f}^{(i)}_{\boldsymbol{\tau}_k} \quad (2)$$

- $\boldsymbol{\omega}^{(i)}$ is the pose weight vector of the ith row, and each element $\omega^{(i)}_{\boldsymbol{\tau}_k}$ represents the fraction of the row exposure time that the camera has stayed in the pose $\boldsymbol{\tau}_k$

Type	Inter-row delay	Pose weight vector ($1 \le i \le M$)
GS	$t_d = 0$	$\omega^{(i)}_{\boldsymbol{\tau}_k} = \begin{cases} 1 & \text{for } k = k_0 \\ 0 & \text{otherwise} \end{cases}$ where k_0 is independent of i
GS+MB	$t_d = 0$	Same $\boldsymbol{\omega}^{(i)}$ for all i
RS	$t_d \neq 0$	$\omega^{(i)}_{\boldsymbol{\tau}_k} = \begin{cases} 1 & \text{for } k = k_i \\ 0 & \text{otherwise} \end{cases}$
RS+MB	$t_d \neq 0$	Different $\boldsymbol{\omega}^{(i)}$ for each i



GS GS+MB RS RS+MB

3 Joint Estimation of Camera Motion and Occlusion

Equivalent representation of (2): $\mathbf{g}^{(i)} = \mathbf{F}^{(i)}\boldsymbol{\omega}^{(i)}$ (3)

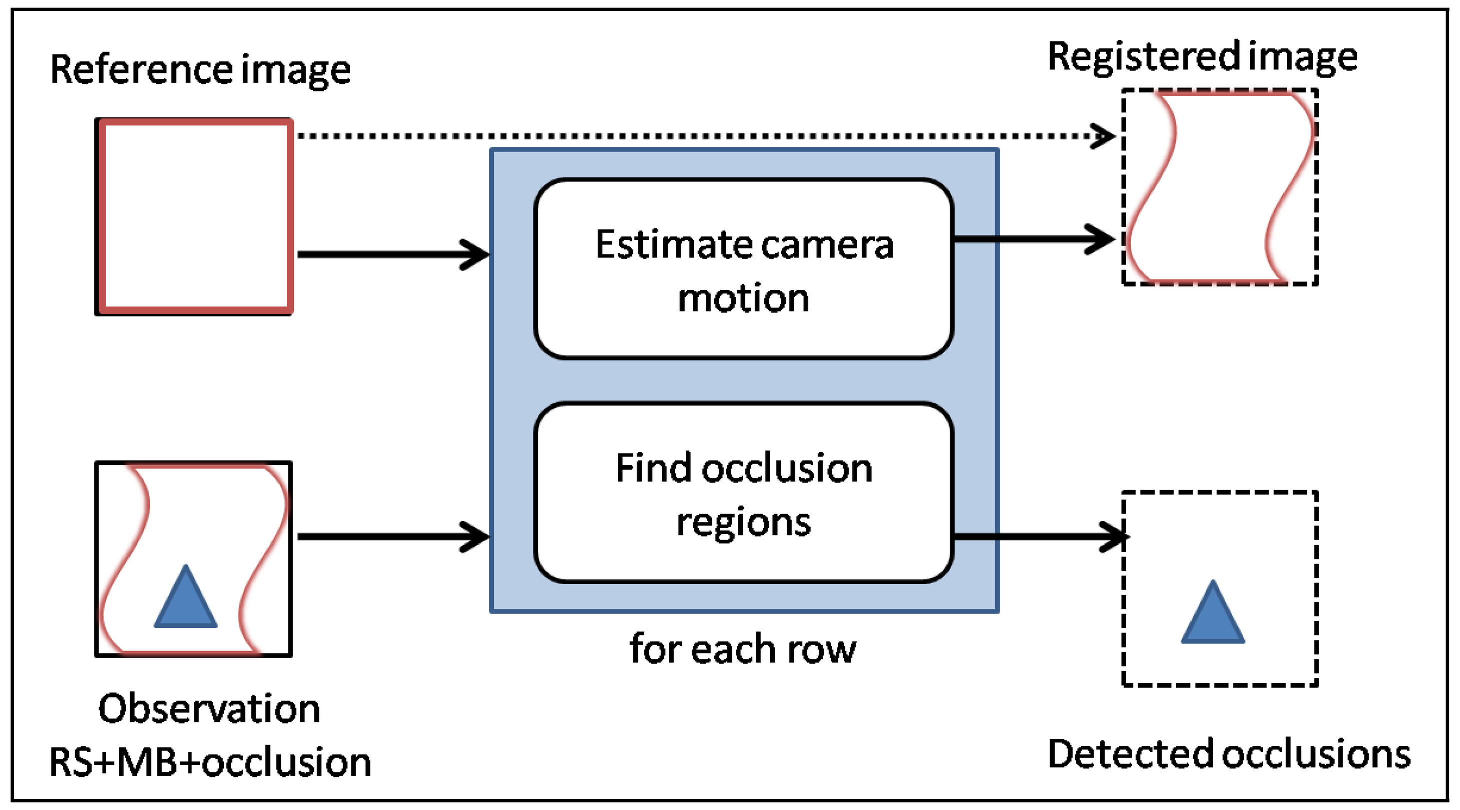
Occlusion model: $\mathbf{g}^{(i)}_{\text{occ}} = \begin{bmatrix}\mathbf{F}^{(i)} & \mathbf{I}_N\end{bmatrix} \begin{bmatrix}\boldsymbol{\omega}^{(i)} \\ \boldsymbol{\chi}^{(i)}\end{bmatrix} = \mathbf{B}^{(i)}\boldsymbol{\xi}^{(i)}$ (4)

- sparsity of both camera motion and occlusion
- non-negativity only on pose weights

$$\tilde{\boldsymbol{\xi}}^{(i)} = \arg\min_{\boldsymbol{\xi}^{(i)}} \left\{ \|\mathbf{g}^{(i)}_{\text{occ}} - \mathbf{B}^{(i)}\boldsymbol{\xi}^{(i)}\|_2^2 + \lambda_1\|\boldsymbol{\omega}^{(i)}\|_1 + \lambda_2\|\boldsymbol{\chi}^{(i)}\|_1 \right\} \quad (5)$$

subject to $\boldsymbol{\omega}^{(i)} \succeq 0$

Block diagram of our change detection method



Pose space adaptation:

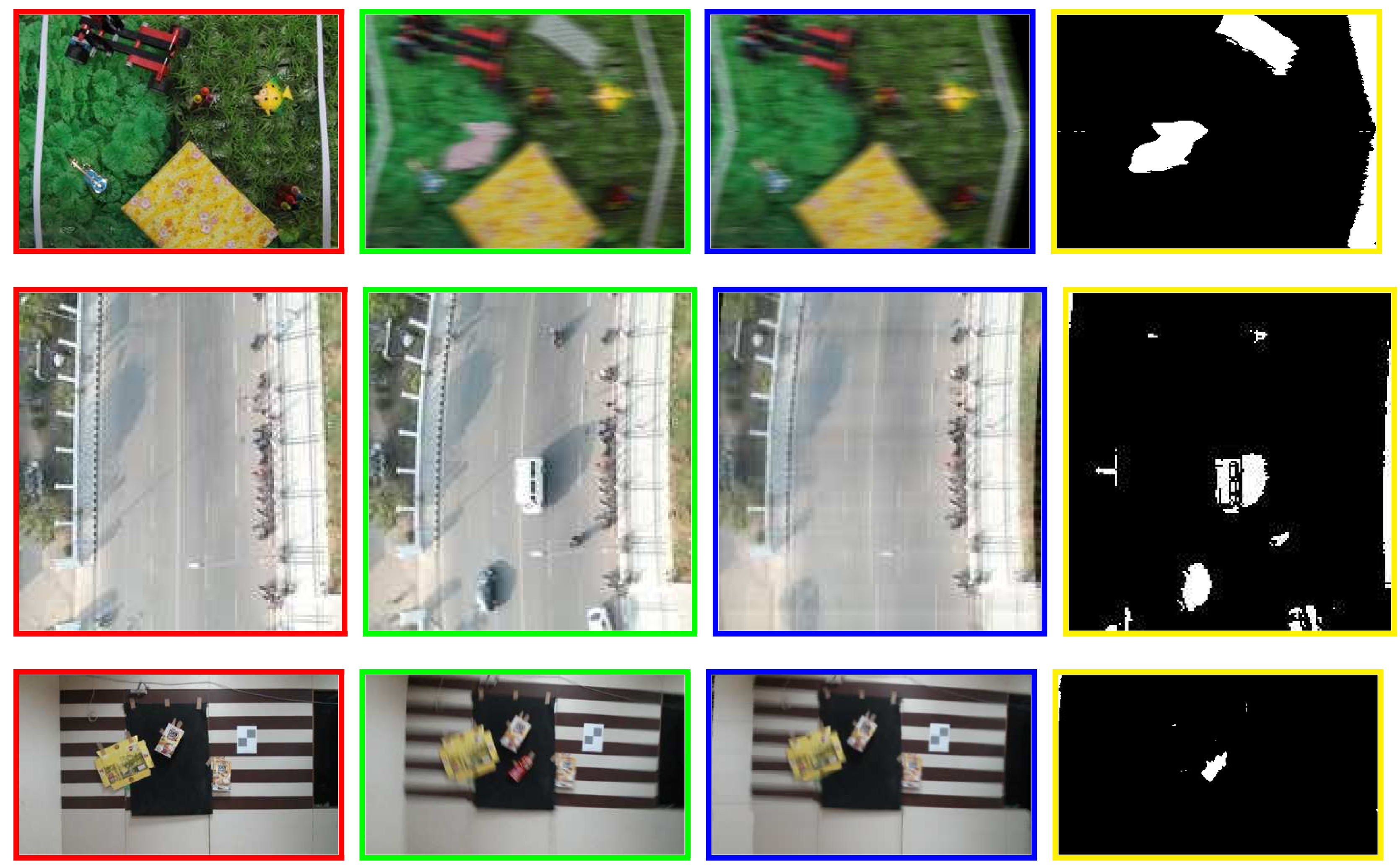
- Start at $i = M/2$ with a pose space $\mathcal{S}^{(M/2)}$. Choose pose space of other rows as neighbourhood of the centroid pose of the nearby row

$$\mathcal{S}^{(i)} = \begin{cases} N(\boldsymbol{\tau}_c^{(i+1)}, \mathbf{b}, \mathbf{s}) & i < M/2 \\ N(\boldsymbol{\tau}_c^{(i-1)}, \mathbf{b}, \mathbf{s}) & i > M/2 \end{cases} \quad (6)$$

$$N(\boldsymbol{\tau}, \mathbf{b}, \mathbf{s}) = \{\boldsymbol{\tau} + q\mathbf{s} : \boldsymbol{\tau} - \mathbf{b} \preceq \boldsymbol{\tau} + q\mathbf{s} \preceq \boldsymbol{\tau} + \mathbf{b}, q \in \mathbb{Z}\} \quad (7)$$

Centroid pose, $\boldsymbol{\tau}_c^{(i)} = \dfrac{\sum_{\boldsymbol{\tau}_k} \omega^{(i)}_{\boldsymbol{\tau}_k}\boldsymbol{\tau}_k}{\sum_{\boldsymbol{\tau}_k} \omega^{(i)}_{\boldsymbol{\tau}_k}}$

4 Experimental Results



Reference image RSMB image Registered image Occlusion regions

http://www.ee.iitm.ac.in/ipcvlab/research/changersmb/