Motion Field and Occlusion Time
Estimation via Alternate Exposure Flow

Anita Sellent, Martin Eisemann and Marcus Magnor

ICCP 2009

Computer Graphics Lab, TU Braunschweig
Optical Flow Approach

- Pinpoint sharp images
- Occlusion unexplained for
- Spatial filtering for motion > 1 pixel
Alternate Exposure Approach

- Correct prefiltering in motion direction
- Occlusion enters long-exposure image formation
- Short images provide high frequency information
Outline

- Image Formation Models
- Computing Motion and Occlusion
- Resulting Motion Fields
- Application to Frame Interpolation
Outline

• **Image Formation Models**
• **Computing Motion and Occlusion**
• **Resulting Motion Fields**
• **Application to Frame Interpolation**
Image Formation Model

- Without occlusion

Center of Projection

Image Plane

Scene Object

$I_1$

$x$

$y_1$

$t = 0$
**Image Formation Model**

- **Without occlusion**

\[
I_1(x, y_1) \quad t = 0
\]
Image Formation Model

- Without occlusion

\[ t = 0 \]
Image Formation Model

- **Without occlusion**
Image Formation Model

- Without occlusion

\[ I_B(x) = \int_0^1 I_1(x + p(x, t)) \, dt \]

\[ I_B(x) = \int_0^1 I_2(x - p(x, t)) \, dt \]
Image Formation Model

- Without occlusion

\[
I_B(x) = \int_0^1 I_1(x + p(x,t)) \, dt
\]

\[
I_B(x) = \int_0^1 I_2(x - p(x,t)) \, dt
\]
Image Formation Model

- Without occlusion

\[
I_B(x) = \int_0^1 I_1(x + p(x, t)) \, dt
\]

\[
I_B(x) = \int_0^1 I_2(x - p(x, t)) \, dt
\]
Image Formation Model

- With occlusion
Image Formation Model

- With occlusion
Image Formation Model

- With occlusion

\[ I_1 \]

\[ I_2 \]

\[ p_1 \]

\[ p_2 \]

\[ x \]

\[ y_1 \]

\[ y_2 \]

\[ t = 0 \]

\[ t = 1 \]
Image Formation Model

- With occlusion

\[
\begin{align*}
I_B(x) &= \int_{t_0}^{t_1} I_1(x + p_1(x, t)) \, dt + \int_{t_0}^{t_1} I_2(x + p_2(x, t)) \, dt
\end{align*}
\]
Image Formation Model

\[ I_B(x) = \int_{t_0}^{t_1} I_1(x + p_1(x, t)) \, dt + \int_{t_0}^{1} I_2(x + p_2(x, t)) \, dt \]
Assumptions

• Linear, constant velocity motion
  \[ p_1(x, t) = tw_a \text{ and } p_2(x, t) = -tw_b \]

• For static scenes \[ I_1 = I_2 = B \]
General Image Formation Model

\[ I_B(x) = \int_0^{t_0} I_1(x-tw_a) \, dt + \int_0^{1-t_0} I_2(x+tw_b) \, dt \]

- **Without occlusion:**
  - \( t_0 \in [0,1] \) arbitrary
  - \( w_a = w_b \)

- **With occlusion**
  - \( t_0 \in [0,1] \) determined by occlusion time
  - \( w_a \neq w_b \)
Outline

- Image Formation Models
- **Computing Motion and Occlusion**
- Resulting Motion Fields
- Application to Frame Interpolation
Computing Motion and Occlusion

- **Step 1: General Parameter Estimation**
  - Levenberg-Marquard algorithm
- **Step 2: Occlusion Detection**
  - Threshold optimization residual
- **Step 3: Foreground/Background Motion**
  - Clustering
- **Step 4: Occlusion Time Estimation**
  - Line search
- **Step 5: Displacement Fields**
Outline

- Image Formation Models
- Computing Motion and Occlusion
- Resulting Motion Fields
- Application to Frame Interpolation
Synthetic Scenes
Synthetic Scenes

Alternate Exposure Flow
## Mean Angular Error

<table>
<thead>
<tr>
<th>Image</th>
<th># images</th>
<th>MAE Lim et al.</th>
<th># images</th>
<th>MAE our method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball, rotation by 3°</td>
<td>14</td>
<td>16.39°</td>
<td>3</td>
<td>5.19°</td>
</tr>
<tr>
<td>Ball, rotation by 5°</td>
<td>25</td>
<td>15.23°</td>
<td>3</td>
<td>5.88°</td>
</tr>
<tr>
<td>Ball, rotation by 10°</td>
<td>50</td>
<td>13.15°</td>
<td>3</td>
<td>6.47°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Image</th>
<th># images</th>
<th>MAE Lim et al.</th>
<th># images</th>
<th>MAE our method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building, rotation by 3°</td>
<td>20</td>
<td>12.61°</td>
<td>3</td>
<td>7.28°</td>
</tr>
<tr>
<td>Building, rotation by 5°</td>
<td>33</td>
<td>11.09°</td>
<td>3</td>
<td>6.97°</td>
</tr>
<tr>
<td>Building, rotation by 10°</td>
<td>66</td>
<td>9.37°</td>
<td>3</td>
<td>8.49°</td>
</tr>
</tbody>
</table>

Real Recordings

- Ptgrey Flea 2 camera
- Built in HDR Mode
- Flycapture Software
Real Recordings
Application to Frame Interpolation

Alternate Exposure Flow

Forward/Backward warping with GT motion
Application to Frame Interpolation

Alternate Exposure Flow

Forward/Backward warping with GT motion
Thank you!
Step 1: General Parameter Estimation

- Assume no occlusion in image
- \( w = w_a = w_b \)
- **Solve:**
  \[
  w(x) = \arg\min_{w \in \mathbb{R}^2} \sum_{i=1}^{N} \left| I_B(x, w, s_i) - B(x) \right|^2 + \left| I_1(x - 0.5w) - I_2(x + 0.5w) \right|^2
  \]
  for each point in image plane
- Levenberg-Marquard algorithm
- Multi-scale approach
Step 2: Occlusion Detection

- **Residual**
  \[ r(x) = \sum_{i=1}^{N} \left| I_B(x, w, s_i) - B(x) \right|^2 + \left| I_1(x - 0.5w) - I_2(x + 0.5w) \right|^2 \]

- Occluded if \( r > \text{threshold} \)
- Consider also 8 neighborhood as occluded

![Diagram of occlusion detection with red and green squares, indicating occluded and not occluded regions.](image)
Step 3: Parameter Interpolation

- Occluded/ Disoccluded pixels have two motion lines assigned $w_a \neq w_b$
- Cluster motions in neighborhood
- Compare superpixels
Step 4: Occlusion Time Estimation

- **Determine** $t_0$ **for occluded pixels**
  \[
  \min_{t_0 \in [0,1]} \left| B(x) - \int_0^{t_0} I_1(x - tw_a) \, dt - \int_0^{1-t_0} I_2(x + tw_b) \, dt \right| + \alpha \left\| \nabla t_0 \right\|_2
  \]

- **Line search**
Step 5: Displacement Fields

- Points that passed through $x$ in long exposure
- Where is a pixel $y$ of $I_1$ reported to be seen?
- RANSAC