Class 3: Advanced Moving Object Detection and Alert Detection
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Outlines

* Moving Object Detection with Distraction Motions
  * Region-based mixture of Gaussians
  * Statistical framework for BGS
  * Motion-based moving object detection

* Interaction between BGS and Tracking
* Moving Object from Moving Cameras
* Real-time alerts of video surveillance
Region-based BGS (Eng et al. 2006) – (1)

Intensity histogram for different points of a typical pool

From Eng et al. 2006
Region-based BGS – (2)

Learning phase:

A sequence of video frames → Generation of background scenes → Building region-based model

Detection phase:

Current frame → "Pseudo-color" compensation (Activated at nighttime)

Region-based model for swimmer → Region-based subtraction and thresholding-with-hysteresis → Object formation based on connected component labelling → Object association and tracking → Background model updating

From Eng et al. 2006
Region-based BGS – (3)

- A sequence of $N_1 \times N_2$ background frames,
- Each frame is divided into $n_1 \times n_2$ non-overlapping blocks ($s \times s$)
- Each block, homogeneous background is generated.
- Compute the mean and covariance matrix of a region $R_{a,b}^k$
Region-based BGS – (4)

\[
\mu_{R_{a,b}^k} = \{\mu_{1R_{a,b}^k}, \ldots, \mu_{dR_{a,b}^k}\}
\]

d=3 (dimension of the color space)

\[
P(x_{i,j} | \mu_{R_{a,b}^k}, \Sigma_{R_{a,b}^k}) = \frac{1}{(2\pi)^{d/2} |\Sigma_{R_{a,b}^k}|^{1/2}} \times \exp \left\{ -\frac{1}{2} (x_{i,j} - \mu_{R_{a,b}^k}) \Sigma_{R_{a,b}^k}^{-1} (x_{i,j} - \mu_{R_{a,b}^k})^T \right\}
\]

From Eng et al. 2006
Region-based BGS \textbf{– (5) Optimizaton:}

\[ P(x_{i,j} | \mu_{R_{a,b}^k}, \sigma_{R_{a,b}^k}) = \prod_{m=1}^{d} \frac{1}{\sqrt{2\pi} \sigma_{R_{a,b}^k}^m} \exp \left\{ -\frac{(x_{i,j}^m - \mu_{R_{a,b}^k}^m)^2}{2(\sigma_{R_{a,b}^k}^m)^2} \right\} \]

\[ \sigma_{R_{a,b}^k} = \{ \sigma_{R_{a,b}^k}^1, \ldots, \sigma_{R_{a,b}^k}^d \} \]

\[ D(x_{i,j} | \mu_{R_{a,b}^k}, \sigma_{R_{a,b}^k}) = \sqrt{\sum_{m=1}^{d} \frac{(x_{i,j}^m - \mu_{R_{a,b}^k}^m)^2}{(\sigma_{R_{a,b}^k}^m)^2}}. \]

From Eng et al. 2006
Region-based BGS – (6)

1. Generating background frames (pixel-based)
   a) temporal vector filter
   b) swimmer skin model
2. Generating initial background model – region-based (S x S)
3. Updating the background models

\[
\mu_{R_{a,b}}^t \leftarrow (1 - \rho)\mu_{R_{a,b}}^{t-1} + \rho \mu_{R_{a,b}}^t \\
\sigma_{R_{a,b}}^t \leftarrow (1 - \rho)\sigma_{R_{a,b}}^{t-1} + \rho \sigma_{R_{a,b}}^t
\]

From Eng et al. 2006
Region-based BGS – (7)

Fig. 4. Generation of a background scene using a temporal vector median filter. (a) A sequence of frames contains foreground swimmers. (b) Generated background scene.
Region-based BGS – (8)

1. Foreground Detection

\[ D_{i,j}^{\min} = \min \{ D(x_{i,j} | \mu R_{a+q,b+r}^k, \sigma R_{a+q,b+r}^k) \} \]

\[ M_{i,j} = \begin{cases} 
0 \text{ background, } & D_{i,j}^{\min} < \alpha \\
1 \text{ foreground, } & \text{otherwise.}
\end{cases} \]

From Eng et al. 2006
Region-based BGS – (9)
Region-based BGS – (10)
Statistical Modeling for BGS – (1)

(Li et al. 2004)
Statistical Modeling for BGS – (2)

- Bayesian framework by using spatial, temporal and spectral information
- Posterior probability for BG and FG:

\[
P_s(b|\mathbf{v}) = \frac{P_s(\mathbf{v}|b)P_s(b)}{P_s(\mathbf{v})} \quad P_s(f|\mathbf{v}) = \frac{P_s(\mathbf{v}|f)P_s(f)}{P_s(\mathbf{v})}
\]

If \( P_s(b|\mathbf{v}) > P_s(f|\mathbf{v}) \), the pixel belongs to BG

V is the feature vector.
Statistical Modeling for BGS – (3)

- Features
  - Color and gradient (static BG)
  - Color co-occurrence between consecutive frame (dynamic BG)
  - Principal features: histogram of features
**Statistical Modeling for BGS – (4)**

5. **Principal feature update**

\[
\begin{align*}
 p_{v}^{t+1}(b) &= (1 - \alpha)p_{v}^{t}(b) + \alpha L_{b}^{t} \\
 p_{v_{i}}^{t+1} &= (1 - \alpha)p_{v_{i}}^{t} + \alpha L_{v_{i}}^{t} \\
 p_{v_{i}|b}^{t+1} &= (1 - \alpha)p_{v_{i}|b}^{t} + \alpha (L_{b}^{t}L_{v_{i}}^{t})
\end{align*}
\]
Statistical Modeling for BGS – (5)
Salient Motion Detection – (1)

**BGS can handle:**
- **✓ Cluttered background**

**BGS cannot handle:**
- **✗ Large Distracting Motion**

(a) Original Image  
(b) Background Subtraction
Handling Distracting Motion / Lighting Changes – (2)
**Salient Motion**: motion that is likely to result from a typical surveillance target, e.g. a person or vehicle traveling with a sense of direction through a scene.

- **Accumulated Temporal Difference**
- **Motion – Optical Flow**
- **Temporal Filter**
- **Multi-sources Fusion**
- **Region Growing**
Salient Motion Detection – (4)

5 Accumulated Temporal Difference:

\[ I_{\text{difference}}(x, y, t + 1) = \begin{cases} 
1, & \text{if } (I_{\text{accum}}(x, y, t + 1) > T) \\
0, & \text{otherwise}
\end{cases} \]

\[ I_{\text{accum}}(x, y, t + 1) = (1 - W_{\text{accum}})I_{\text{accum}}(x, y, t) + W_{\text{accum}}|I(x, y, t + 1) - I(x, y, t)|. \]
Salient Motion Detection – (5)

Motion Extraction – Optical Flow:

\[ I_{t+1}(x + d) - I_t(x) = 0 \]

\[
E = \sum_{x \in R} [I_{t+1}(x + d) - I_t(x)]^2
\]

\[
d_{n+1} = d_n + \left\{ \sum_{x \in R} \left( \frac{\partial I}{\partial x} \right)^T \left|_{x+d_n} \right. [I_t(x) - I_{t+1}(x)] \right\}
\]

\[
\left[ \sum_{x \in R} \left( \frac{\partial I}{\partial x} \right) \left( \frac{\partial I}{\partial x} \right)^T \left|_{x+d_n} \right. \right]^{-1}
\]
Salient Motion Detection – (6)

- Temporal Filter:

\[ F_1 \quad \rightarrow \quad l_t \quad \rightarrow \quad l_{t+1} \quad \rightarrow \quad \cdots \quad \rightarrow \quad l_{t+n} \quad \rightarrow \quad F_n \]

- Optical flow

- Multi-sources Fusion

\[
I_{\text{salient}}(x, y, t) = I_{\text{difference}}(x, y, t) \cap (I_{X-\text{temporal}}(x, y, t) \cup I_{Y-\text{temporal}}(x, y, t))
\]
Salient Motion Detection – (7)
Salient Motion Detection – (8)
Salient Motion Detection – (9)

- Salient Motion Detection
  - Deal with large distracting motion
  - Assumptions of object motion
  - Cannot detect the object when it is stop

- Need interaction between higher level processing -- tracking
BGS with higher level feedback

- Frame level
  - Reset BGM
- Tracking
  - Hold an object
  - Heal an object
- Time
  - Different BGM for different time
BGS and Tracker Interaction

- BGS get feedback from Tracker
  - Slow moving object tracking
  - Stopped object healing
- Different situations
  - Tracker sends “Heal request”, BGS will push the region to BG model
  - Tracker sends out “Unheal request” and provide the image which BGS can use it for BG model, BGS update the BG Model.
  - Tracker sends out “Hold a region”, BGS will not update that region.
  - BGS sends out “Heal request” (auto heal process), tracker decides if do it.
Moving Object Detection from moving camera – (1)

1. Find good feature to track
2. Track features
3. Classify foreground and background features
4. Decide region of foreground object
Moving Object Detection from moving camera – (2)

5. Finding good feature to track
5. Shi and Tomasi ‘s method

Images from Martin Chang
Moving Object Detection from moving camera – (3)

⑤ Track features – Optical follow

Images from Martin Chang
Moving Object Detection from moving camera – (4)

- Classify foreground and background feature points
  - Optical flow
    - Moving direction of feature
    - Length of moving direction
Affine Motion Model for Background Registration

\[
\begin{pmatrix}
u \\
v
\end{pmatrix} =
\begin{pmatrix}
a_0 \\
a_3
\end{pmatrix} +
\begin{pmatrix}
a_1 & a_2 \\
a_4 & a_5
\end{pmatrix}
\begin{pmatrix}
x \\
y
\end{pmatrix}
\]

- The affine model describes the vector at each point in the image
- Need to find values for the parameters that best fit the motion present
- Point feature tracker for correspondence between frame pairs
- Iterative reweighted least squares to avoid the features in moving objects (P. W. Holland et al, Robust regression using iteratively reweighted least squares, Communications in Statistics, A6(9):813-827, 1977)
Alerts for Video Surveillance – (1)

5 User defined alerts
   5 Generating real-time alerts from video analytics
   5 Generating alerts based on the index – speeding, big car, …

5 Learning-based alerts
   5 loitering, …
   5 Recalculate alerts
Alerts for Video Surveillance – (2)

- Motion detection (Trigger alarm when motion detected)
- Directional motion detection (Trigger alarm when motion in the direction detected)
- Trip wire (Trigger alarm when cross boundary)
- Abandoned object (Trigger alarm when abandoned object detected)
- Object removal (Trigger alarm when monitored object removed)
- Camera blind/removal (Trigger alarm when camera being blocked/moved)
- Compound Alarms – (sequential or temporal)
- Region alert
- Camera move stopped
- Slip/fall
- Running
- Gathering (become crowded)
- Speeding
Alerts for Video Surveillance – (3)

**Tracking-based Alerts**

- (1) Directional motion
- (2) Trip wire

**BGS-based Alerts**

- (1) Motion detection
- (2) Abandoned object
- (3) Object removal
- (4) Camera blind/removal

**Diagram:***

- Video Input
- Video Recoder
- Index writer
- DB

- Uninterested region definition
- Background Subtraction
- Tracking
- Object Classification
- Alert Detection
Motion Detection Alert

- Can be tracking based or only BGS based
- Region of interest
- Min detected object size:
- Max detected object size
- Number of frames with motion
  - Alarm will be triggered after detecting number of frames with motion
- Min number of moving objects
  - Input at the parameter window (1, 2..)
Motion Detection
Camera Blind/moved Alert: – BGS-based

- Time for pre-event video recording (in seconds):
- Sensitivity to camera movement
  - high
  - Medium high
  - Medium
  - Medium low
  - low
Camera Move/blind
Directional Motion Alert

- Tracking based
- Motion-based – crowded environment
Directional Motion Alert – Tracking-based

- Region of interest
- Define Direction of Motion
- Accuracy degrees (how many degrees can be tolerated)
- Object type
- Object Color
- Object Speed
Directional Motion Detection
Trip Wire Alert – Tracking-based

1. Define Trip Wire:
2. Min detected object size:
3. Max detected object size
4. Object type (person, car)
5. Object Speed
6. Object color
Trip Wire Alert
Abandoned/removed Object Detection – (1)

5 Detect Static Object
   ⁵ Using 2nd Gaussian Model

5 When to heal the static region
   ⁵ When the static region start to shrink

5 Detect heal type
   ⁵ Region growing for BG image and input image by using the heal region as seeds (abandoned, removed, unclear)

5 Match the region of the input image and the heal region

5 Trigger the alert if it meet all the requirements of the alert definition
Region of interest
Min detected object size (in pixels):
Max detected object size (in pixels)
Waiting time before trigger the alarm (in seconds):
   Input at the parameter window (1, 2..)
Abandoned/removed Object Detection – (3)

(a) Frame 343 & 344
(b) Frame 569 & 570
(c) Frame 664 & 665
Abandoned or removed Object Detection – (4)
Abandoned/removed Object Detection – (5)
Abandoned/removed Object Detection – (6)
Abandoned/removed Object Detection – (7)
Abandoned Object Detection – (8)
Object Removal Alert – BGS-based

- Region of monitoring
- Sensitivity to changes in the monitoring region:
  - high
  - Medium high
  - Medium
  - Medium low
  - low
Object Removal – museum mode
Summary

- Moving Object Detection with Distraction Motions
  - Region-based mixture of Gaussians
  - Statistical framework for BGS
  - Motion-based moving object detection
    - Salience Motion
- Interaction between BGS and Tracking
- Moving Object from Moving Cameras
- Real-time alerts of video surveillance
References – (1)


References – (2)


5 Ying-Li Tian and Arun Hampapur, “Robust Salient Motion Detection with Complex Background for Real-time Video Surveillance,” IEEE Workshop on Motion and Video Computing, Jan, 2005.


5 J. Shi and Carlo Tomasi, “Good Features to Track" CVPR’94, pp. 593-600.

5 P. W. Holland et al, Robust regression using iteratively reweighted least squares, Communications in Statistics, A6(9):813-827, 1977