Change Detection: Current State of the Art and Future Directions

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Outline

• Motivation & problem statement
• Change detection techniques
  – Radiometric adjustment
  – Geometric adjustment
  – Stochastic modeling and hypothesis testing
• Future directions
  – Probabilistic approach
  – Geometric approach
What’s Change Detection?

- Open your eyes wide, find 5 differences
What’s Change Detection?

• Open your eyes wide, find 5 differences
Motivations (1)

• In medical diagnosis, change detection can help detect diseases.
Motivations

- In remote sensing, change detection can help assessing damage from natural disaster.

Biloxi before Hurricane Katrina

Biloxi after Hurricane Katrina
Motivations

• In video surveillance, change detection can help detecting suspicious activities (activity monitoring).
Problem Statement

Change Detection
Technical Challenges

• Change detection is an ill-posed problem
  – since it is hard to define “changes” between images
    • Need to serve specific purposes (surveillance, disease diagnosis, etc.); hard to quantify meaningful changes

• Need to remove insignificant changes
  – Lighting variation
    • Bright under sunshine
    • Dark under cloudy weather
  – Camera motion
    • Changes caused by camera motion are insignificant

Detecting changes is challenging!
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Typical Procedure of Change Detection

Image1

Intensity Adjustment

Geometry Adjustment

Image2

Intensity Adjustment

Geometry Adjustment

Stochastic modeling & hypothesis testing

Change Mask
Radiometric Adjustment – Why?

- Eliminate lighting variations
Radiometric Adjustment – Why? (2)

- Mitigate noise

X-ray image of circuit board corrupted by salt-and-pepper noise

Noise reduction with a $3 \times 3$ median filter
Radiometric Adjustment – How?

- Histogram matching: make two images have the same histogram
- Homomorphic filtering: 

\[ I(x) = I_l(x)I_o(x) \]

\[ \ln I(x) = \ln I_l(x) + \ln I_o(x) \]

\[ I_o(x) = \exp\{HPF(\ln I(x))\} \]
Noise Mitigation

- Intensity modeling: \( I(x) = I_l(x)I_o(x) + N(x) \)
- Gaussian noise
  - Frame/local spatial averaging
- Speckle noise – salt and pepper noise
  - Widely exist in coherent imagery, such as SAR, ultrasound
    - PDF:
      \[
      p(z) = \begin{cases} 
      P_a & z = a \\
      P_b & z = b \\
      0 & \text{else}
      \end{cases}
      \]
  - How to mitigate it?
    - Median filter
      \[
      f(x, y) = \text{median}\left\{\{g(s, t)\}_{(s, t) \in S_{xy}}\right\}
      \]
Median Filtering Example
Geometric Adjustment – Why?

• A.k.a. image registration
• Camera may move

Need to align images into the same coordinate system
Geometric Adjustment – How?

- Need Intrinsic & extrinsic camera parameters
- General steps

Diagram:
- Feature Detection
- Feature Matching
- Transformation Model Estimation
- Transformation
Geometric Adjustment – Example

- Input images:

- Adjusted Images:
Stochastic Modeling and Hypothesis Testing

Image 1

Image 2

Image Differencing

Stochastic Modeling

Hypothesis Testing (Change Mask Decision)

Labeled Images

Change Mask
Stochastic Modeling Process

Model Selection

Labeled Images

Statistical Learning

Parameters of the Model

Model

Analytic form

Parameters
Hypothesis Test

- Hypotheses
  - $H_0$: no change
  - $H_1$: change
- Testing:
  maximum likelihood

\[ k = \arg \max_{k \in \{0,1\}} p(x \mid H_k) \]
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Probabilistic Approach – Flowchart

Image1
- Intensity Adjustment
- Geometry Adjustment
- Image Differencing
  - Classification With Hidden Markov Tree Model

Image2
- Intensity Adjustment
- Geometry Adjustment

Homomorphic Filtering
- Optical Flow
- Change Mask
Statistic Model – One Pixel

- **MAP criterion:**
  \[ \hat{x} = \arg \max_x P(x | f) = \arg \max_x p(f | x) P(x) \]

- **Limitation:**
  - It does not consider spatial correlation
Statistc Model – Multiple Pixel

• MAP criterion: \( \hat{x} = \arg \max_{x} \prod_{i=1}^{N} p(f_i | x_i) \bullet P(x) \)

where \( x = [x_1, x_2, ..., x_N]^T \)

• Advantage: consider spatial correlation

• Limitation: complexity is too high
  – \( 2^N \) possible \( x \), i.e., \( O(2^N) \) complexity, if \( x_i \) has 2 possible values.
Hidden Markov Tree Model

• What is hidden Markov tree (HMT)?
• Advantages of HMT:
  – Utilization of spatial correlation
  – Can use Viterbi algorithm whose complexity is $O(N^2)$
Classification

- **Decision:** MAP criterion

\[
\hat{x}_i = \arg \max_x P(x | f) = \arg \max_x P(x_i | x_{\rho(i)}, f) P(x_{\rho(i)} | x_{\rho(\rho(i))}, f) \ldots P(x_{\text{root}} | f), \text{ for } \forall i \in V
\]

- **How to calculate:**

\[
P(x_i | x_{\rho(i)}, f) = \frac{P(x_i, x_{\rho(i)} | f)}{P(x_{\rho(i)} | f)}, \forall i \in V
\]

**Diagram:**

1. **Training** → Feature Extraction → Belief Propagation → MAP-based Decision Device
2. **Testing** Image → Feature Extraction → Belief Propagation → MAP-based Decision Device

\[
\hat{x}_i
\]
Training

\[ P(f_i | x_i = m) = \sum_{g=1}^{G} \pi_g(m)N(f_i; \mu_g(m), \Sigma_g(m)) \]

\[ P(x_i | x_{p(i)}) = \frac{1}{K} \sum_{k=1}^{K} \frac{P(x_i, x_{p(i)} | f^{(k)})}{P(x_{p(i)} | f^{(k)})} \]

\[ f_i = \begin{bmatrix} r_i \\ g_i \\ b_i \\ w_i \end{bmatrix} \]

\[ \max_{\pi, \mu, \Sigma} \prod_{n=1}^{N} P(f_i^{(n)} | x_i^{(n)}) \]

\[ P(f_i | x_i) \]

\[ P(x_i | f) \]

\[ P(x_i, x_{p(i)} | f) \]
Experimental Results

Training samples:

Ground

Sky

Testing images:

Output of classifier
Experimental Results (2)

Input Images

Change Mask
Geometric Approach: Motion-based Change Detection

- Does motion mean change?
  - Global motion is caused by camera motion
  - Local motion is caused by object motion, which is useful.

![Diagram](image)
Motion-based Change Detection (2)

• How to define 2D motion?
  – Translation
    \[ u = x + t_x \]
    \[ v = y + t_y \]
  – Affine motion
    \[ u = a_0 + a_1 x + a_2 y \]
    \[ v = b_0 + b_1 x + b_2 y \]
  – Bilinear motion
    \[ u = a_0 + a_1 x + a_2 y + a_3 xy \]
    \[ v = b_0 + b_1 x + b_2 y + b_3 xy \]
  – Projective mapping
    \[ u = \frac{a_0 + a_1 x + a_2 y}{1 + c_1 x + c_2 y} \]
    \[ v = \frac{b_0 + b_1 x + b_2 y}{1 + c_1 x + c_2 y} \]
Motion-based Change Detection (3)

- Single-body motion model \( f_i(x, M_i) = 0 \)
- Multibody motion model
  \[ g(x, M) = f_1(x, M_1) \cdot f_2(x, M_2) \cdots f_n(x, M_n) = 0 \quad \text{(for } \forall x) \]
- Multibody motion estimation: estimate \( M \)
  - \( n \) and \( M \) can be obtained linearly after embedding \( x \) into a higher-dimensional space
- Motion segmentation: \( M \rightarrow \{M_i\}_{i=1}^{n} \)
- Refine motion models
- Do it recursively until it converges.
Experimental Results

Camera motion

Object motion
Grand Challenges in Image Processing & Computer Vision
Change Detection in 3D Space

- Change detection in 3D space is important for homeland security and military.
- Key component of detection & classification of moving personnel in DARPA VisiBuilding program.
- Challenges: need better understanding & exploitation of physics and imaging modalities.

See through walls, using radar, MMW, X-ray, acoustic, UWB, SAR, neutron, gamma-ray, etc.
Real-time 3D Imaging of Interior of Building & Underground Structure

• Critical for urban warfare
  – Provide critical information for commanders to make tactical decisions; help assess enemy course of action

• Need synergistic efforts from different areas
  – Wall/ground penetrating sensors
  – Microwave imaging
  – Vision processing
  – 3D image reconstruction
  – Circuits
Super Resolution in Satellite Imaging

• Can we improve the resolution of current satellite imagery by a factor of 10 or even 100?

• Potential impact: why this is important?
  – Able to see details never available previously, e.g., recognize human, car, objects of size ~1m
  – Particularly important for intelligence, Department of Defense, and homeland security

• Possible solutions
  – Multi-view image processing of multiple satellite images
  – New imaging techniques based on physics
Thank you!