A keypoint approach for change detection between SAR images based on graph theory

presented by

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Introduction

Context

Change detection between two SAR images

Applications:

- Understanding/evaluating land-cover changes occurring after a natural or anthropic disaster
- Identifying/monitoring land-use development over time, etc.
- SAR imagery: capable of acquiring data under any atmosphere and illumination conditions

Reference methods:

- *Ratio-based detectors:* mean ratio (MR), log-ratio (LR), fusion of MR+LR
- *Higher order statistics approaches:* Pearson-based/cumulant-based Kullback-Leibler distance, etc.

$\longrightarrow$ constrained to the evaluation of dense neighborhoods around image pixels
$\longrightarrow$ large-size windows need to be considered!

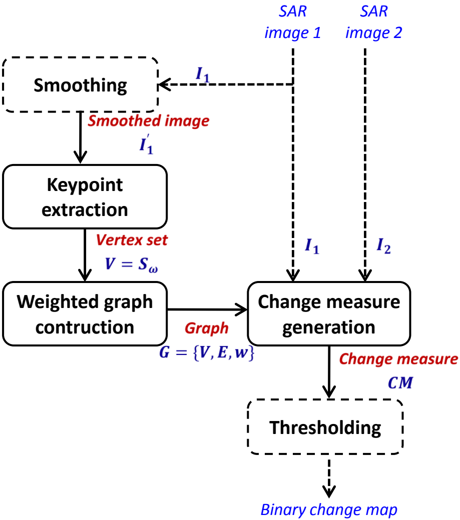
Introduction

Objective of this work

- **Non-dense approach** based on the interaction of characteristic points (i.e. keypoints) to measure changes
- **Graph-based model** $\longrightarrow$ encode both image intensity and geometry information
- Experiments on real SAR image data
  - Qualitative and quantitative evaluation
  - Comparison to reference approaches for validation

Contents

Methodology - Proposed framework



Methodology - Non-dense approach based on characteristic points

- **Our recent work** $\Rightarrow$ texture representation and description using a set of characteristic points, not all image pixels
  - Texture $\Rightarrow$ **spatial arrangement** of pixels holding some **intensity variations**
  - Can be approximated by the local maximum/minimum pixels
  - Relevant to large-size images without requirement of stationarity hypothesis
- **In this work** $\Rightarrow$ exploit the local maximum pixels to represent and perform change detection algorithm

$$p \in S_{\omega}^{\max}(I) \Leftrightarrow \left\{ p = \operatorname{argmax}_{q \in \mathcal{N}_{\omega}(p)} I(q) \right\},$$

where $\mathcal{N}_{\omega}(p)$: set of neighboring pixels of p inside $\omega \times \omega$ search window.

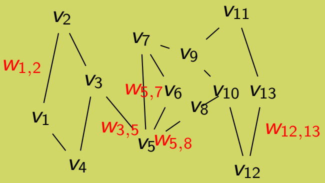
- **Advantages:**
  - Easy to be extracted
  - Appear together with any variation of intensity (i.e. presence of texture)
  - Good density and distribution on the image plane

M.T. Pham, G. Mercier, J. Michel, *Pointwise graph-based local texture characterization for VHR multispectral image classification*, IEEE-JSTARS, vol. 12(5), 2015.

Methodology - Weighted graph and characteristics

Weighted graph

A graph $\mathcal{G} = (V, E, w)$ consists of:



- V: vertex set (i.e. nodes)
- E: set of edges between vertices
- w: edge weights involving vertex similarity

Characteristics

Adjacency matrix
(i.e. matrix of weights)

$$\mathcal{W} = \begin{pmatrix} 0 & w_{1,2} & \cdots & w_{1,N} \\ w_{2,1} & 0 & \cdots & w_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ w_{N,1} & w_{N,2} & \cdots & 0 \end{pmatrix}$$

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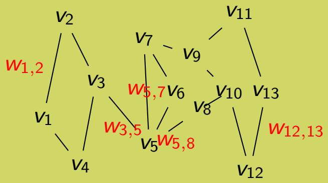
Methodology - Weighted graph and characteristics

Weighted graph

A graph $\mathcal{G} = (V, E, w)$ consists of:



- V: vertex set (i.e. nodes)
- E: set of edges between vertices
- w: edge weights involving vertex similarity

Characteristics

Degree matrix

$$\mathcal{D}_{ii} = \sum_j \mathcal{W}_{ij}$$

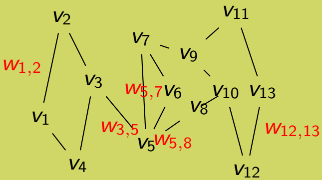
$$\mathcal{D}_{ij} = 0, \forall j \neq i$$

$$\mathcal{D} = \begin{pmatrix} \sum_k w_{1,k} & 0 & \cdots & 0 \\ 0 & \sum_k w_{2,k} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sum_k w_{N,k} \end{pmatrix}$$

Methodology - Weighted graph and characteristics

Weighted graph

A graph $\mathcal{G} = (V, E, w)$ consists of:



- V: vertex set (i.e. nodes)
- E: set of edges between vertices
- w: edge weights involving vertex similarity

Characteristics

Laplacian matrix

$$\mathcal{L} = \mathcal{D} - \mathcal{W}$$

$$\mathcal{L} = \begin{pmatrix} \sum_k w_{1,k} & -w_{1,2} & \cdots & -w_{1,N} \\ -w_{2,1} & \sum_k w_{2,k} & \ddots & -w_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ -w_{N,1} & -w_{N,2} & \cdots & \sum_k w_{N,k} \end{pmatrix}$$

Methodology - Weighted graph and characteristics

Characteristics

Denote $f = \{f(n) \in \mathbb{R}, n = 1 \ldots N\}$:

$$(\mathcal{W}f)(n) = \sum_{k \sim n} w(n,k) f(k)$$

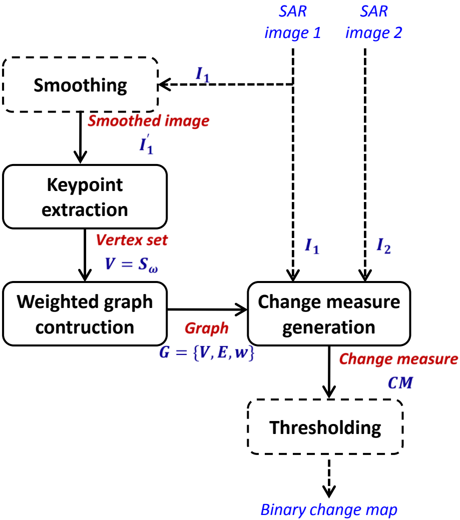
$\longrightarrow$ concentration of information diffused from neighboring vertices
$\longrightarrow$ filtering operator on graph signal

$$(\mathcal{L}f)(n) = \sum_{k \sim n} w(n,k) \left[f(n) - f(k) \right]$$

$\longrightarrow$ local difference operator on graph signal

D. I. Shuman, S. K. Narang, P. Frossard, A. Ortega and P. Vandergheynst, *The emerging field of signal processing on graphs: Extending high-dimensional data analysis to networks and other irregular domains*, IEEE Sig. Proc. Society, vol. 30, no. 3, pp. 83-98, May, 2013.

Methodology - Proposed framework



Methodology - Graph for keypoints

Graph construction

- Vertex set = set of extracted max keypoints
- Each vertex connects to K closest neighbors
- Weight computation:

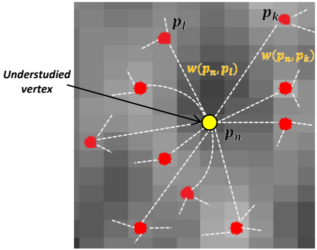
$$w(p_n, p_k) = e^{-\gamma\left[\mathrm{dist}(p_n, p_k)\right]},$$

$$\forall (p_n, p_k) \in E$$

- Employing log-ratio distance:

$$\mathrm{dist}(p_n, p_k) = \left| \log \frac{\mu_1(p_n)}{\mu_1(p_k)} \right|$$

$\mu_1(p_n)$ (resp. $\mu_1(p_k)$): the mean intensity of the pixel patch around vertex p_n (resp. p_k) from the first image I_1.



$$(\mathcal{W}f)(p_n) = \sum_{p_k \sim p_n} w(p_n, p_k) f(p_k)$$

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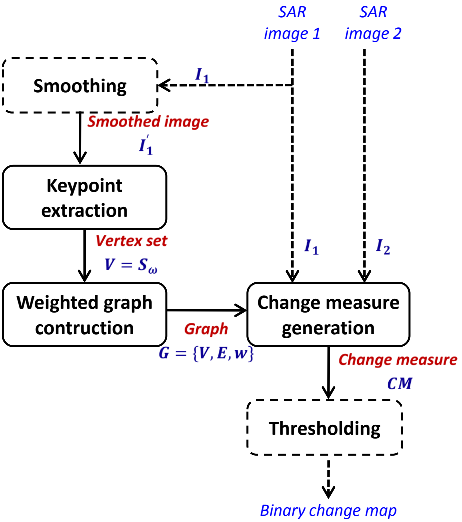
Methodology - Proposed framework



Methodology - Generation of change measure

Proposed strategy

Change measure = the **coherency/compatibility** of radiometric information captured by the vertices of graph $\mathcal{G}$ from two images.

- Two signals on graph $\mathcal{G}$ capturing radiometric information from I_1 and I_2:

$$f_1 = [\log \mu_1(p_1), \log \mu_1(p_2), \dots, \log \mu_1(p_N)]^T,$$
$$f_2 = [\log \mu_2(p_1), \log \mu_2(p_2), \dots, \log \mu_2(p_N)]^T.$$

- Change measure at keypoint p_n:

$$\begin{aligned}
\mathrm{CM}(p_n) &= \Big|\Big|(\mathcal{W}f_1)(p_n) - (\mathcal{W}f_2)(p_n)\Big|\Big|_1 \\
&= \left| \sum_{p_k \sim p_n} w(p_n, p_k) \log \mu_1(p_k) - \sum_{p_k \sim p_n} w(p_n, p_k) \log \mu_2(p_k) \right| \\
&= \sum_{p_k \sim p_n} w(p_n, p_k) \left| \log \frac{\mu_1(p_k)}{\mu_2(p_k)} \right|.
\end{aligned}$$

Contents

Experimental study - Data sets

Dataset 1

- Two 800 × 400 images acquired by *Radarsat-1* satellite, 10-m resolution
- Before and after the eruption of Nyiragongo vocalno, DR. of Congo
- Semi-urban zone near *Goma* international airport

Before eruption

After eruption

Change mask

Experimental study - Data sets

Dataset 2

- Series of 10 *Radarsat-2* images, 5-m resolution
- An intensively agricultural area in Chartres, France
- Two extracted ROIs of 1000 × 850 pixels

Chartres, France


ROI from Image acquired 25/4/2010


ROI from Image acquired 19/5/2010

Experimental study - Evaluation criteria

Reference methods

- Ratio-based detectors: mean-ratio (MRD), log-ratio (LRD)
- Higher order statistics: Gaussian-based Kullback-Leibler (GKLD), Cumulant-based Kullback-Leibler (CKLD)

Evaluation criteria

- False alarm (**FA**) rate and good detection (**GD**) rate
- Percentage of total errors (**TE**) consisting of false alarms and missed detections
- Percentage of overall accuracy (**OA**)
- **ROC** (Receiver operating characteristics) curve $\longrightarrow$ plots the GD rate in function of FA rate

Experimental study - Results

Dataset 1

- Two 800 × 400 images by *Radarsat-1* satellite, 10-m resolution
- Before and after the eruption of Nyiragongo vocalno, DR. of Congo

Before eruption

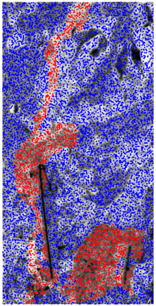
After eruption

Change mask

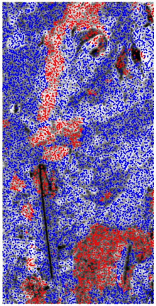
Experimental study - Results

Dataset 1

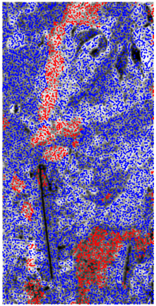
- Compared to reference methods: MRD and CKLD
- Window size 35×35 pixels, $K = 50$ for graph construction



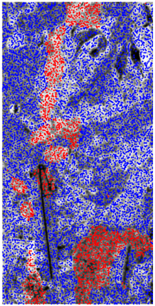
Mask at keypoints



MRD



CKLD

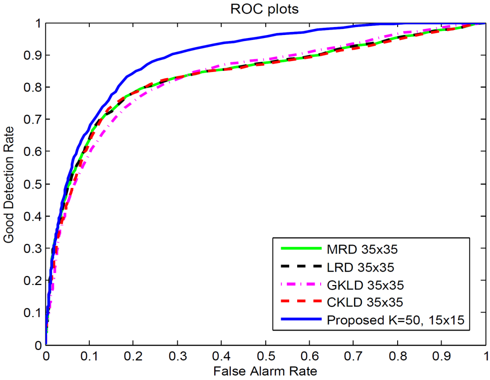


Proposed method

Experimental study - Results

Dataset 1

- **ROC plots** compared to MRD, LRD, GKLD and CKLD
- Window size 35×35 pixels, $K = 50$ for graph construction



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Experimental study - Results

Comparison of False Alarm rate (P_{FA}), Good Detection rate (P_{GD}), percentage of Total Errors (P_{TE}) and percentage of Overall Accuracy (P_{OA})

Dataset 1 ($N_c = 2011$ points, $N_u = 7534$ points)

Thresholding Method	Detector	False Alarms (points)	Missed Detections (points)	Good Detections (points)	P_{GD}/P_{FA}	P_{TE} (%)	P_{OA} (%)
K-means	MRD	804	690	1321	6.1555	15.65	84.35
	LRD	686	775	1236	6.7501	15.31	84.69
	GKLD	662	886	1125	6.3666	16.22	83.78
	CKLD	533	959	1052	7.3944	15.63	84.37
	Proposed	549	795	1216	**8.2980**	**14.08**	**85.92**
Otsu	MRD	840	652	1359	6.0611	15.63	84.37
	LRD	701	768	1243	6.6430	15.39	84.61
	GKLD	733	835	1176	6.0106	16.43	83.57
	CKLD	554	939	1072	7.2493	15.64	84.36
	Proposed	583	766	1245	**8.0004**	**14.13**	**85.87**
KI	MRD	723	754	1257	6.5134	15.47	84.53
	LRD	688	775	1236	6.7304	15.33	84.67
	GKLD	534	979	1032	7.2402	15.85	84.15
	CKLD	766	739	1272	6.2212	15.77	84.23
	Proposed	645	722	1289	**7.4870**	**14.32**	**85.68**

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Dataset 2

- Series of 10 *Radarsat-2* images, 5-m resolution
- An intensively agricultural area in Chartres, France
- 2 ROIs of 1000 $\times$ 850 pixels

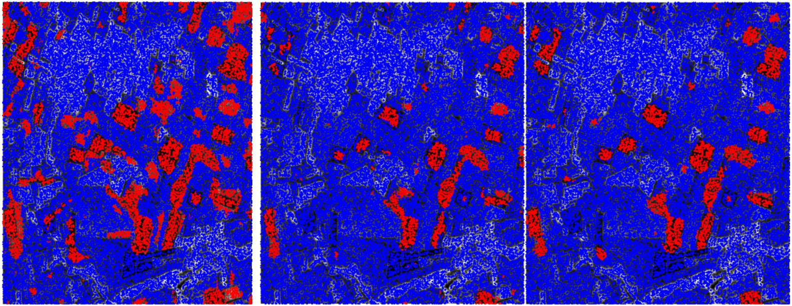
Chartres, France


ROI from Image acquired 25/4/2010


ROI from Image acquired 19/5/2010

Dataset 2

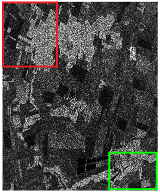
- Compared to reference meththods: MRD and GKLD
- Window size 35 $\times$ 35 pixels, $K = 50$ for graph construction



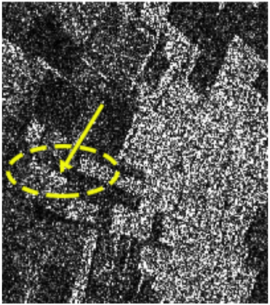
MRD GKLD Proposed method

Dataset 2

- Compared to reference meththods: MRD and GKLD
- Zoomed results for RED zone



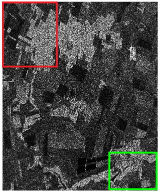
Red cut from image 1

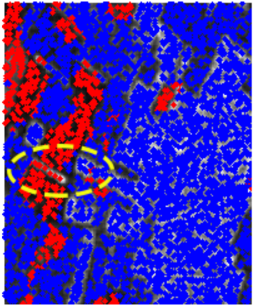


Red cut from image 2

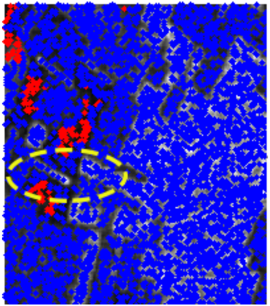
Dataset 2

- Compared to reference meththods: MRD and GKLD
- Zoomed results for RED zone

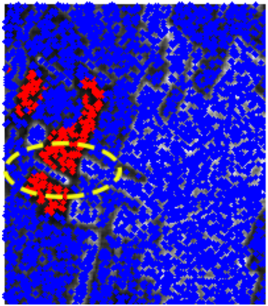




MRD



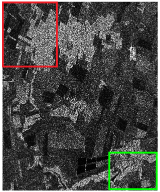
GKLD



Proposed method

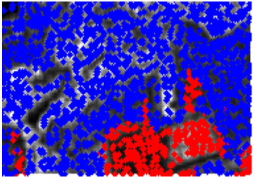
Dataset 2

- Compared to reference meththods: MRD and GKLD
- Zoomed results for GREEN zone

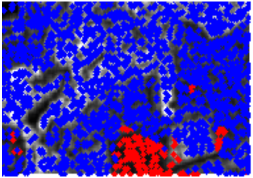


Green cut from image 1

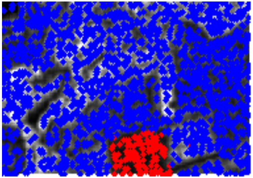
Green cut from image 2



MRD



GKLD



Proposed method

Contents

Conclusion and future work

Conclusion

- Change detection strategy by a non-dense approach based on the interaction between characteristic points encoded by a graph model
- Superior performance compared to reference methods
- Robust to different thresholding techniques

Future work

- Investigation on multi-date SAR data
  $\Rightarrow$ study major changes overtime
  $\Rightarrow$ understand the development of agricultural crops, forest/urban zones, movement of glaciers, etc.

Thanks for your attention!