Bright Line Detection in COSMO-SkyMed SAR Images of Urban Areas

P.T.B. Brett and R. Guida

Surrey Space Centre
University of Surrey
Guildford, UK
{p.brett,r.guida}@surrey.ac.uk

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Overview

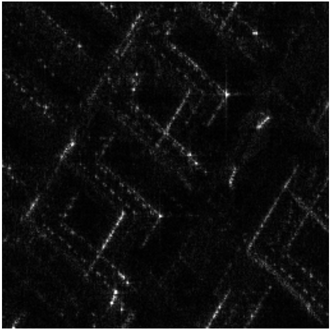
1. Background of research
2. Previous work in the area
3. Bright lines from ridge detection
4. Classification of ridges
5. Results
6. Applications & future work
7. Conclusions

Background

Why bright lines?

Bright lines are a characteristic feature of SAR amplitude images of urban areas:

- Specular reflection lines from gabled roofs
- Double-reflection lines from walls and level ground



SAR image processed from COSMO-SkyMed product © Agenzia Spaziale Italiana 2009.

Background

Concept for research

Use SAR to detect urban earthquake damage on building-by-building scale.

Challenges

- Locating buildings in a SAR image
- Determining if they are damaged

Background

Determining damage

- Building shape parameters can be extracted from double-reflection lines (Franceschetti *et al.* 2007, Guida *et al.* 2010).
- Assuming same electromagnetic properties, changes to double reflection lines indicate changes to building shape.
- Strong specular lines also significant (e.g. gabled roofs).

Locating buildings in SAR image

- Still no definitive solution
- First step: is detecting bright lines enough?

Previous work

Two main approaches to line detection in the SAR literature:

1. Hough transform
2. Directional filter banks

Previous work

Hough transform

- Long history of use in SAR (Wood 1985, and many others).
- High-quality results.
- Scaling problems:
  - very large numbers of lines;
  - small lines relative to image size.
- Detection of curved lines greatly increases computational cost.

Previous work

Directional filters

- Used in banks (usually 4-6 directions).
- Applied e.g. for SAR road network extraction (Tupin *et al.* 1998, Gamba *et al.* 2006).
- Fine angular discrimination hard to achieve.
- “Brute force” approach, but effective.

Ridge detection

Bright lines as ridges

- Bright line detection interpreted as a *ridge detection* problem.
- Natural to use the *height definition* of a ridge to find bright lines (Eberly *et al.* 1994)
- Further developed into an algorithm for image ridge detection: *scale-space ridge detection* (Lindeberg 1998).
- Includes quantitative metrics for ridge strength.
- As far as we know, not in SAR literature?!

Ridge detection

Advantages

1. Highly local (only need image data from close to point to detect ridge)
2. Admits to easy parallel implementation (multicore processors/clusters)

Challenges

1. SAR images often very large; excessive resources needed for multi-scale ridges.
2. Assembling ridge points into full lines.

This paper: novel application of *single-scale* detection of *points on bright lines*.

Ridge detection

Let $f : \mathbb{R}^2 \to \mathbb{R}_+$ be a SAR amplitude image, and let $\boldsymbol{x}$ be a point in the image plane.

Three steps to detect ridges in f:

1. Scale-space generation.
2. Metric generation.
3. Ridge point detection.

Ridge detection

Scale-space generation

- *Scale-space representation* of the image: $L : \mathbb{R}^2 \times \mathbb{R}_+ \to \mathbb{R}$.
- Obtained by $L(\boldsymbol{x}; t) = f \star g(\boldsymbol{x}; t)$.
- g is a Gaussian kernel of variance t.
- Highest frequency components in image determine feature scale.

Ridge detection

Scale-space generation

- *Scale-space derivatives* of the image: $L_{x^\alpha y^\beta}(\boldsymbol{x};t)$
- Obtained by $L_{x^\alpha y^\beta}(\boldsymbol{x};t) = L \star^\alpha \Delta(\boldsymbol{x}) \star^\beta \Delta^T(\boldsymbol{x})$
- Δ is a derivative operator.

Implementation

g and Δ: separable discrete scale-space (DSS) formulation (Lim & Stiehl 2004).

Metric generation

- Consider the negated Hessian matrix of L:

$$W(\boldsymbol{x};t) = -\begin{bmatrix} L_{xx}(\boldsymbol{x};t) & L_{xy}(\boldsymbol{x};t) \\ L_{xy}(\boldsymbol{x};t) & L_{yy}(\boldsymbol{x};t) \end{bmatrix}$$

- Let k_1, k_2 and $\boldsymbol{v}_1, \boldsymbol{v}_2$ be the eigenvalues and eigenvectors of W such that $|k_1| > |k_2|$.
- Let (p, q) be a local coordinate system aligned with $\boldsymbol{v}_1, \boldsymbol{v}_2$.
- Two metrics required: $L_{pp}(\boldsymbol{x};t)$ and $L_p(\boldsymbol{x};t)$.

Ridge detection

Ridge point detection

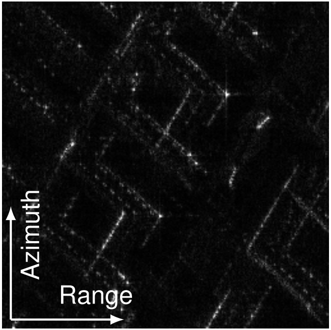
- A ridge point $\boldsymbol{x}_0$ must satisfy:

$$L_p\left(\boldsymbol{x}, t\right) = 0, \qquad L_{pp}\left(\boldsymbol{x}; t\right) < 0.$$

- Ridge points found by:
  1. Linear interpolation along rows and columns of image to find zeros of L_p;
  2. Sign test of interpolated value of L_{pp}.

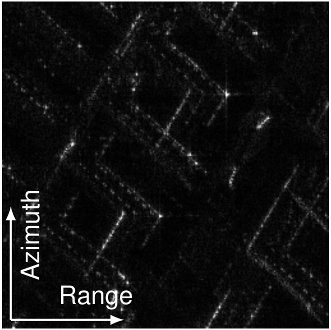
Ridge detection

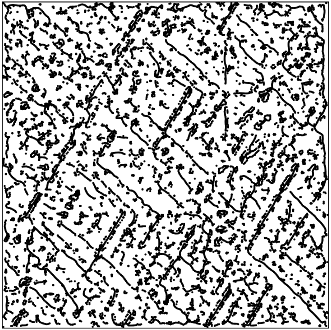
Initial results



Ridge detection

Initial results

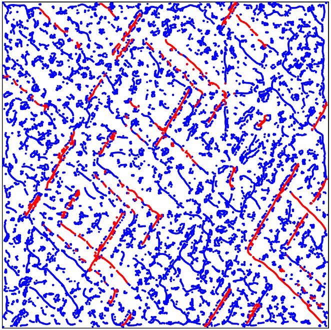




Ridge classification

Naïve Bayesian classifier

- Simple "proof of concept" approach
- Two feature variables:
  1. Brightness of ridge point (interpolated from image)
  2. Strength of ridge point (γ-normalised square principle curvature difference)
- Trained using supervised classification (right).



Ridge classification

Ridge brightness

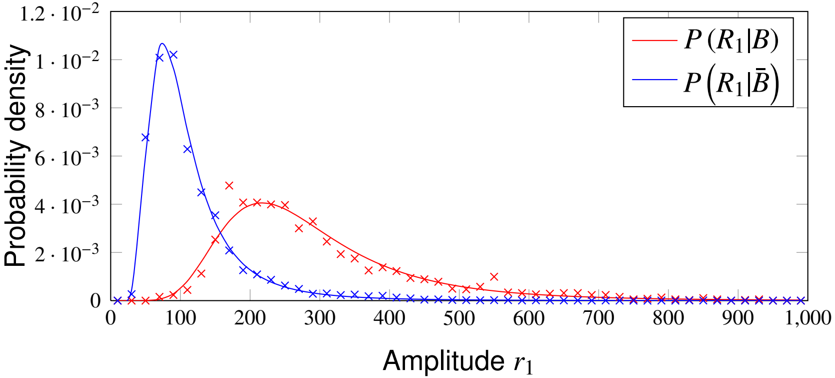
- First feature variable (R_1)
- Linearly interpolated from amplitude image.
- Modelled by established $\mathcal{G}_A^0$ distribution (Frery *et al.* 1997, Tison *et al.* 2004).

$$f_{R_2}(x) = \frac{2n^n \lambda^{-\alpha} \Gamma(n-\alpha)}{\Gamma(n)\Gamma(-\alpha)} \frac{x^{2n-1}}{(\gamma + nx^2)^{n-\alpha}}$$

Ridge classification

Ridge brightness

- Fitted to training data using log-moment method (Tison *et al.* 2004)



Ridge classification

Ridge strength

- Second feature variable (R_2).
- Metric is γ-*normalised square principle curvature difference* (Lindeberg 1998).

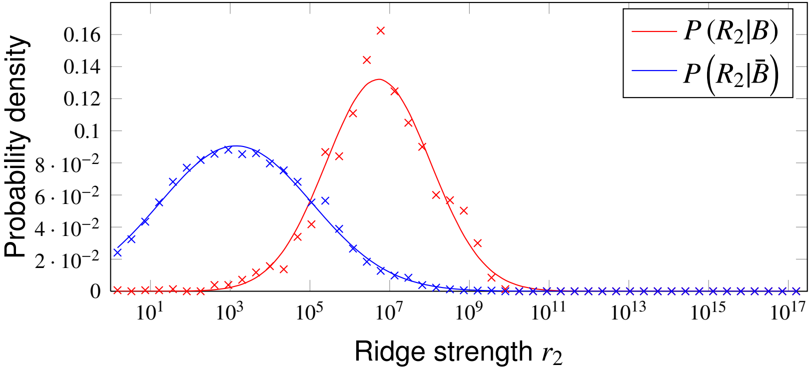
$$\mathcal{N}_{\gamma-norm}\, L(\boldsymbol{x}; t) = t^{4\gamma} \left(L_{pp}^2 - L_{qq}^2 \right)^2$$

- Strong response to elongated structures; low blob response.
- γ is a constant which normalises the metric for scale. In this case, $\gamma = 1$ is used.

Ridge classification

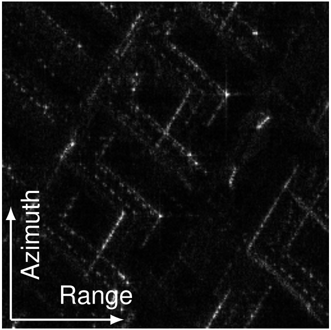
Ridge strength

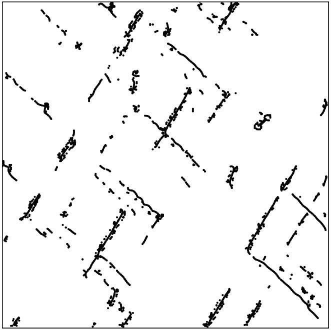
- Authors propose modelling ridge strength by log-normal distribution $R_2 \sim \ln N\left(\mu, \sigma^2\right)$.



Results

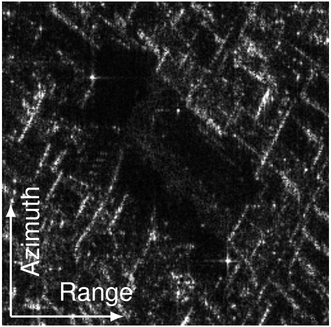
L’Aquila: barracks area

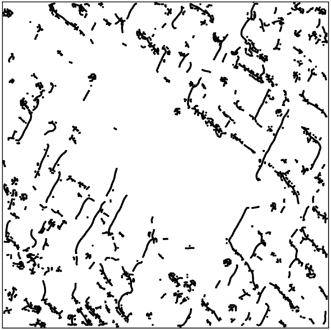




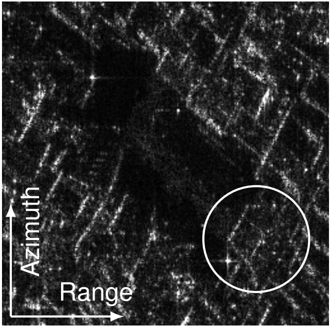
Results

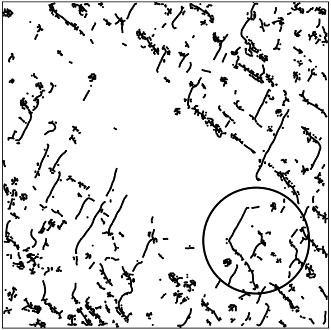
L'Aquila: market square area



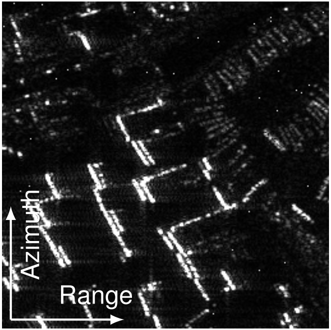


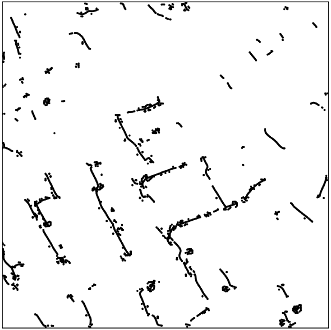
L'Aquila: market square area





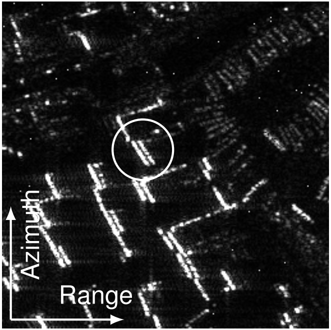
Haiti: Container stacks near harbour

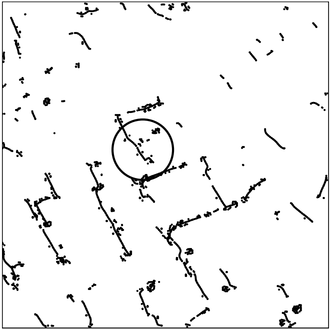




Results

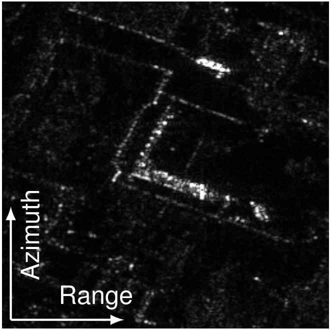
Haiti: Container stacks near harbour

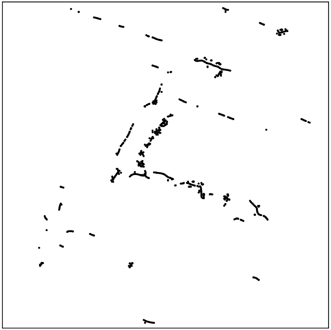




SAR image processed from COSMO-SkyMed product © Agenzia Spaziale Italiana 2009.

Haiti: Notre Dame cathedral





Applications & future work

Applications

- Earthquake damage detection (original concept);
- Land use classification;
- Ship detection;
- Road network extraction (using *dark* line detection).

Future work

- Detection based not on points but whole lines (good progress).
- Better models for feature variables and less ‘naïve’ classification.
- Multi-scale extraction and very large datasets.
- Focus on applications.

Conclusions

- Ridge detection has great potential for SAR applications.
- Good alternative to existing SAR line extraction methods.
- With classification, promising bright line extraction method.
- Demonstrated with application to very high resolution SAR data.

An approach to earthquake damage detection using this technique will be presented on Wednesday at 09:30 (Session S3).