Geometry-Based SAR Curvilinear Feature Selection for Damage Detection

P.T.B. Brett and R. Guida

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

24th April 2012

Overview

1. Background of research and previous work
2. Outline of approach
3. Building feature model
4. Curvilinear features
5. Noise feature model
6. Damage detection application
7. Results
8. Applications & future work
9. Conclusions

Background

Concept for overall research project

Use amplitude Synthetic Aperture Radar (SAR) to detect urban earthquake damage at the level of individual buildings.

Challenges

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

Background

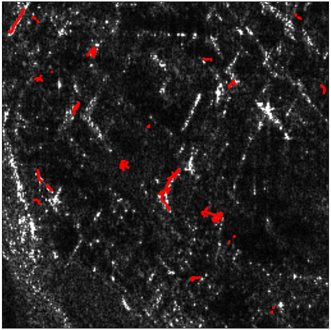
Damage to buildings

- Building shape parameters can be extracted from double-reflection lines (Franceschetti *et al.* 2007, Guida & Iodice 2010).
- Assuming same electromagnetic properties, changes to double reflection lines indicate changes to building shape.
- Strong specular lines also significant (e.g. gabled roofs).
- Previously applied for earthquake damage detection (Guida *et al.* 2010, Guida & Brett 2011); mostly manual approach.

Background

Damage to buildings

Example of manual/point-based results (Guida & Brett 2011):



Objective: automate currently-manual steps.

Background

Locating buildings

Wide variety of approaches in literature, e.g.:

- DEM-based InSAR (Simonetto *et al.* 2005)
- Multiple-aspect InSAR (Thiele *et al.* 2007)
- Detection and matching of bright lines and shadow areas (Ferro *et al.* 2010).

Various problems with existing approaches, including:

- Need for InSAR
- Need for multiple SAR acquisitions
- High computational complexity

Outline of approach

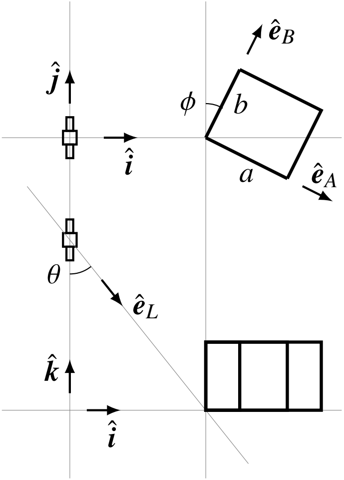
Concept: locate a building's double-reflection line(s) instead of the building itself.

Use priors derived from building geometry to classify bright curvilinear features.

In practice:

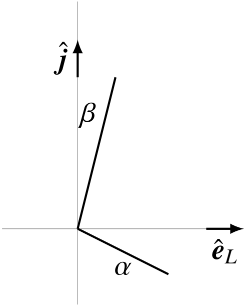
1. Extract bright curvilinear features from SAR image
2. Choose the ones that “look like” double-reflection lines using an idealised building model.

Building feature model



- Trivial isolated building
- Smooth sides, rough level ground
- Height h
- Double-reflection pattern depends on ϕ and θ

Double reflection line parameters

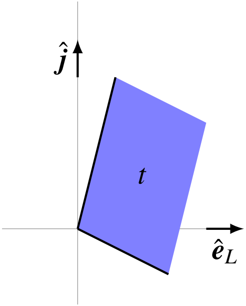


Lengths α and β:

- Complex functions of ϕ
- Inconvenient model parameters

Building feature model

Double reflection line parameters



Projected area t in SAR image:

$$t = C_t \cdot ab$$

where C_t is a constant:

- *Independent* of ϕ
- Function of image resolution
- Function of look angle θ

Building feature model

Prior probability distributions

- Let $A = a$ and $B = b$ be random variables for building dimensions
- Let $T = t$ be a random variable for projected area.

Then T takes a product distribution with p.d.f.:

$$f_T(t|C_t) = \frac{1}{C_t} \int_0^\infty \frac{1}{b} f_A\left(\frac{t}{C_t b}\right) f_B\left(b\right)\, \mathrm{d}b\,.$$

Building feature model

Prior probability distributions

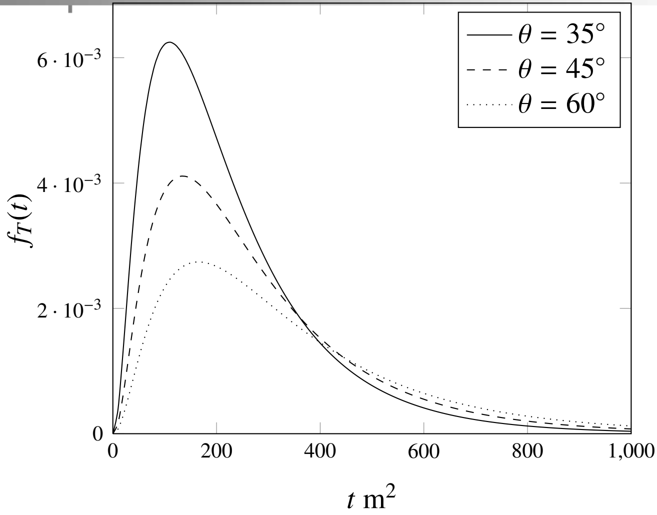
For *proof of concept*, necessary to construct a suitable prior:

- Assume A and B are i.i.d.
- Let $A \sim \Gamma(k, m)$. Then:

$$f_T(t|k, m, C_t) = \frac{2}{t\, C_t\, \Gamma^2(k)} \left(\frac{t}{C_t m^2}\right)^k K_0\left(2\sqrt{\frac{t}{C_t m^2}}\right).$$

- This is a variant of the K distribution (Redding 1999)
- We chose e.g. $A \sim \Gamma(4, 5)$ (mean side 20 m).
- N.b. *not* derived from empirical geographical data.

Building feature model



Example prior p.d.f. of projected area t for various look angles.

Curvilinear features

Extraction algorithm

- Variety of curvilinear feature detectors (e.g. Steger, Lindeberg scale-space)
- Steger detector common in urban SAR literature (e.g. Ferro *et al.* 2010).

We chose single-scale variant of Lindeberg ridge detector (Lindeberg 1998, Brett & Guida 2011) for speed & scability.

Curvilinear features

Projected area estimation

- Let $C = \{\boldsymbol{r}_0, \ldots, \boldsymbol{r}_N\}$ be an N-step feature with $\boldsymbol{r}_0 = \boldsymbol{0}$.
- If C is double-reflection line from idealised building, then:

$$\tilde{t} \approx R_e \cdot \sqrt{3R_g^2}$$

where:

1. $R_e = |\boldsymbol{r}_N|$ is end-to-end distance
2. $R_g^2 = \frac{1}{NR_e^2} \sum_{n=0}^{N-1} |\boldsymbol{r}_n \times \boldsymbol{r}_N|^2$ is radius of gyration.

Noise feature model

Noise processes

- Most significant noise process is speckle noise
- In single-look images, Rayleigh noise (multiplicative) (Frery *et al.* 1998)

Monte-Carlo experiments

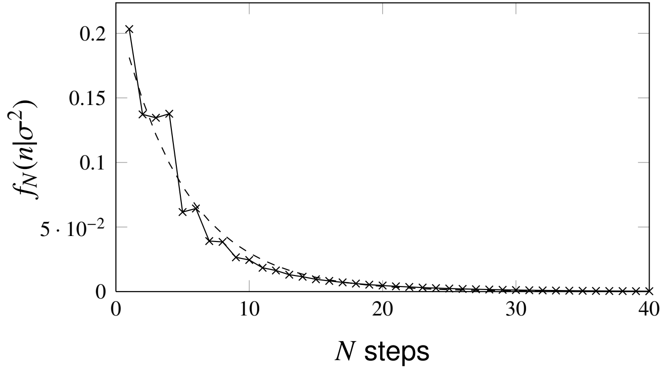
- Extraction of 10^8 features from synthetic images.
- Results indicate *geometric* approximation is reasonable:

$$f_N(n|\rho) = (1-\rho)^{n-1}\rho$$

- Found that with Lindeberg detector, ρ is scale-dependent.

Noise feature model

Example: for scale $\sigma^2 = 8$, maximum likelihood estimate $\tilde{\rho} = 0.121$.



MAP model selection

Two models for a feature C:

- $\mathcal{H}_1$ – C is a double-reflection line, with $\tilde{t} \approx R_e \cdot \sqrt{3R_g^2}$;
- $\mathcal{H}_0$ – C is noise-induced.

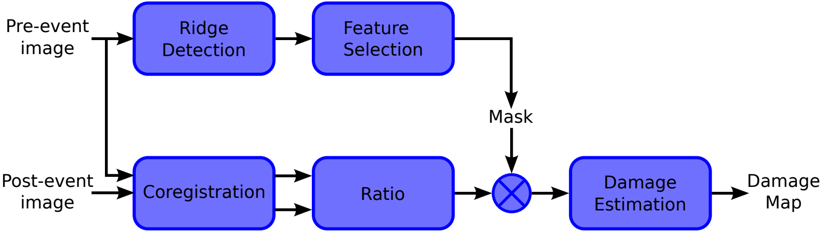
Maximum a posteriori (MAP) decision rule:

$$\ln \frac{p\left(\mathcal{H}_1\right)}{p\left(\mathcal{H}_0\right)} + \ln \frac{p\left(C|\boldsymbol{\vartheta}_1, \mathcal{H}_1\right)}{p\left(C|\boldsymbol{\vartheta}_0, \mathcal{H}_0\right)} \underset{\mathcal{H}_0}{\overset{\mathcal{H}_1}{\gtrless}} 0$$

where $\boldsymbol{\vartheta}_1 = \{k, m, \theta\}$ and $\boldsymbol{\vartheta}_0 = \{\rho\}$ are the corresponding parameter sets. We estimate $p(\mathcal{H}_1) \approx 0.05$.

Damage detection application

Process flowchart



Damage detection application

Change severity metric

- Based on double-reflection line building height change estimator (Guida *et al.* 2010)
- Cannot be certain that all selected features are double-reflections.

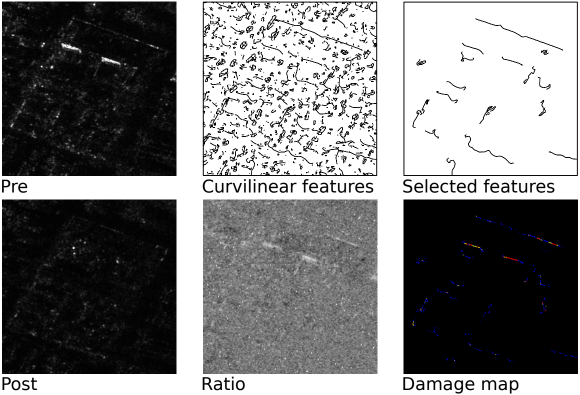
For pre- and post-event cross-sections σ_1 and σ_2, change severity:

$$\tilde{d} = \left(1 - \tilde{A}\frac{\sigma_2}{\sigma_1}\right)$$

where $\tilde{A} = E\left[\sigma_1/\sigma_2\right]$.

Results

Supreme Court building, Port-au-Prince, Haiti



Results

Supreme Court building, Port-au-Prince, Haiti

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

Applications & future work

Applications

- Other urban change detection applications;
- Land use classification.

Future work

- Improved building model based on GIS data;
- Theoretical basis for curvilinear featurs from noise;
- Integration with other damage detection methods.

Conclusions

- Effective approach to selecting relevant curvilinear features.
- Fully unsupervised method; no manual steps required.
- Low computational complexity and high speed.
- Successfully applied to earthquake damage detection.
- Useful complement to other damage detection techniques.

UNIVERSITY OF SURREY

EPSRC
Pioneering research and skills

asi
agenzia spaziale italiana