Ultrasonic Strain Image Made by Speckle Tracking of B-mode Image

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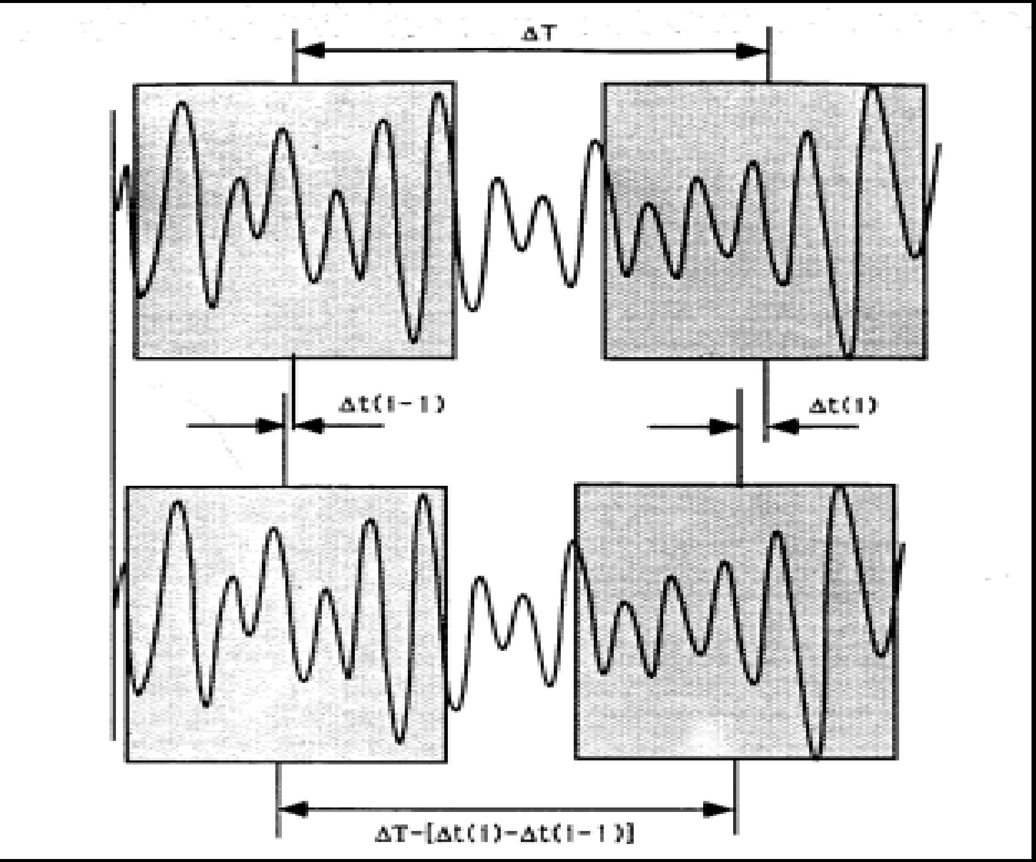
Introduction

- Elasticity imaging can provide a significant adjunct to current diagnostic ultrasonic methods
- Most elasticity imaging is derived by RF data and few by envelope data.
- RF data elasticity imaging is more sensitive; envelope data is less noisy under larger strain

Strain estimation by RF data

Cross correlation of consequent A-line

$$s(i) = \frac{\Delta t(i) - \Delta t(i-1)}{\Delta T}$$



Strain estimation by envelope data

--Speckle tracking of B-mode image

- 1D-cross correlation of consequent column of pixels (like A-line of RF data)(Ophir) : lateral displacement is hard to detect.

- 2D-Block matching algorithm (Levinston, 1994; Yeung, 1997), time costing
full search and multi-level methods

Goal of this project

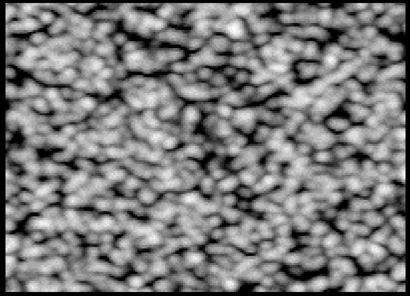
- studying the differences of 1D and 2D methods
- studying the differences of full search and multilevel speckle tracking method
- searching other possible strain estimator

Materials and Methods

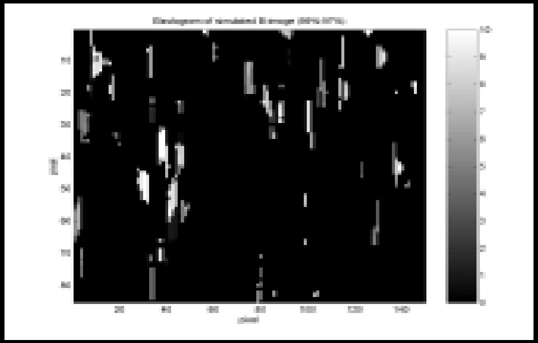
- Target: B-mode images
  - simulated data set
  - breast phantom
  - clinical breast tumor
- Method: 1D and 2D speckle tracking

Result-I

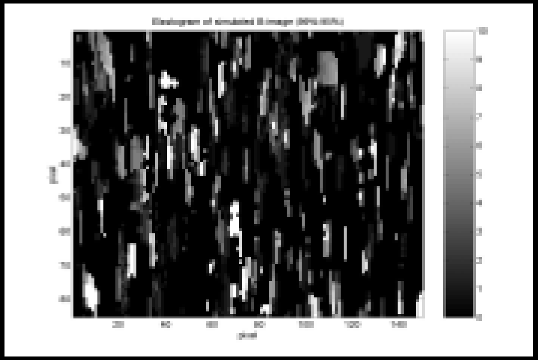
- Comparison of Elastogram1 (1D and 2 D)



1D

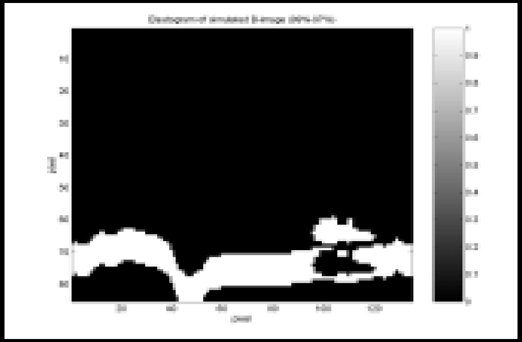


99-97%

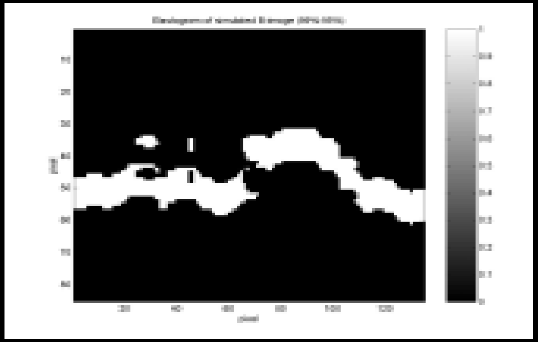


99-95%

2D



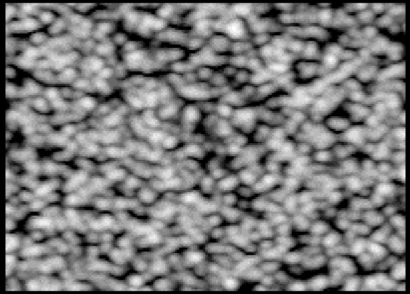
99-97%



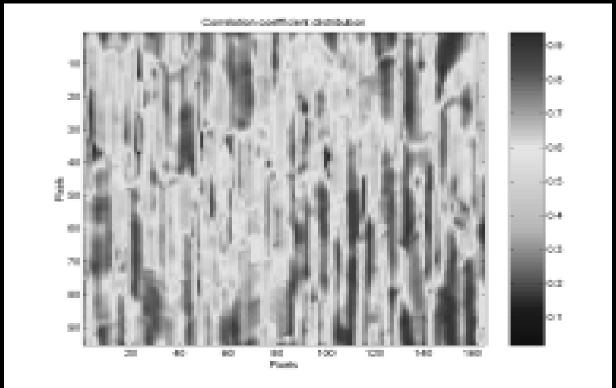
99-95%

Result-I

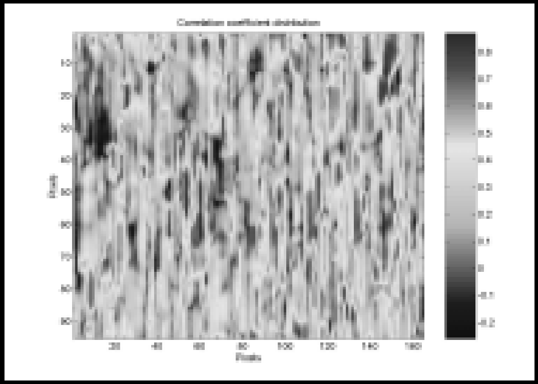
- Comparison of correlation coefficients distribution (1D and 2 D)



1D

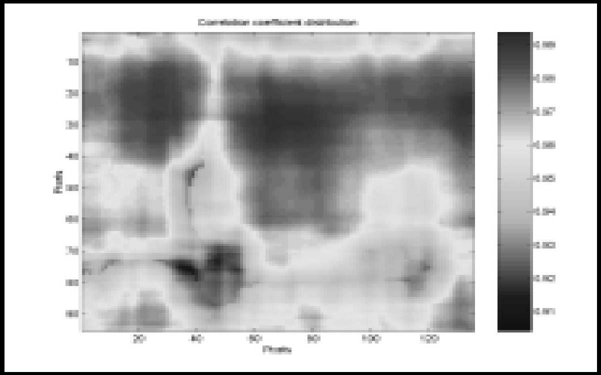


99-97%

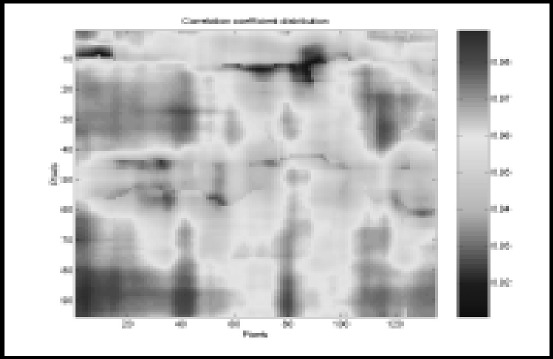


99-95%

2D



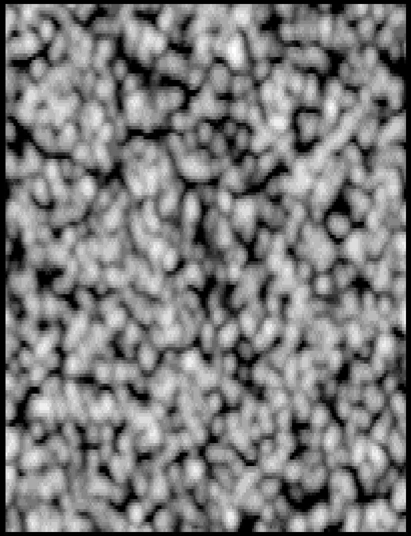
99-97%



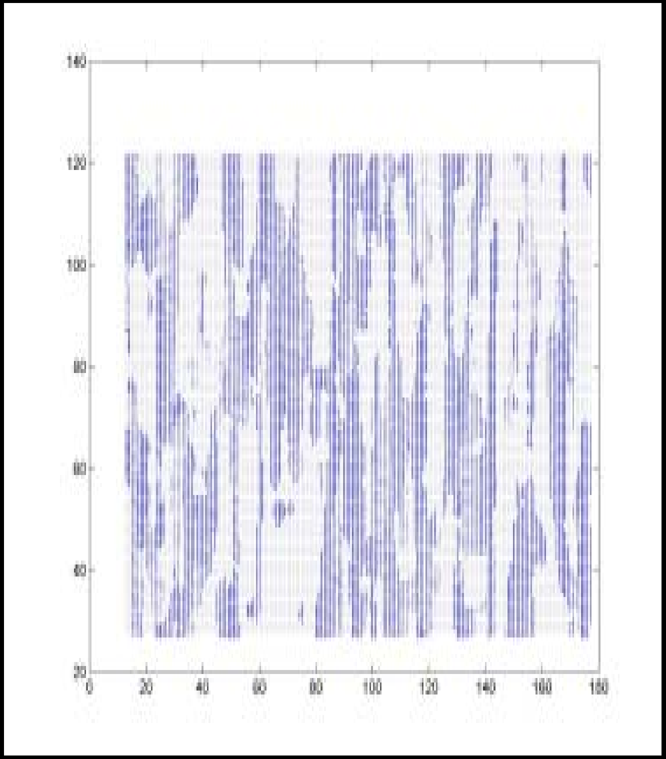
99-95%

Result-I

- Comparison of arrow direction distribution (1D and 2 D)

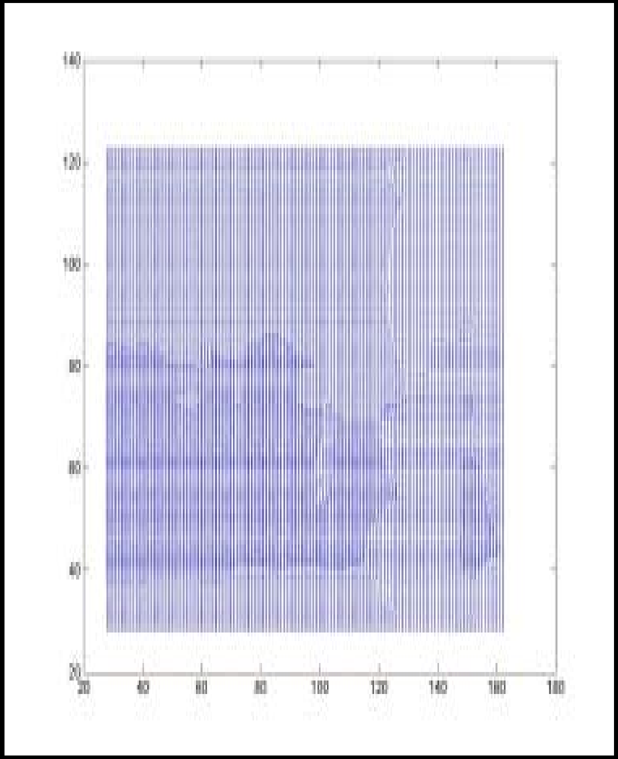


1D



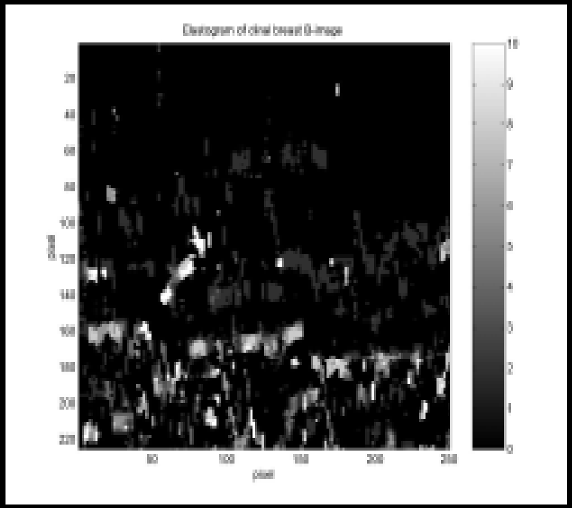
99-95%

2D

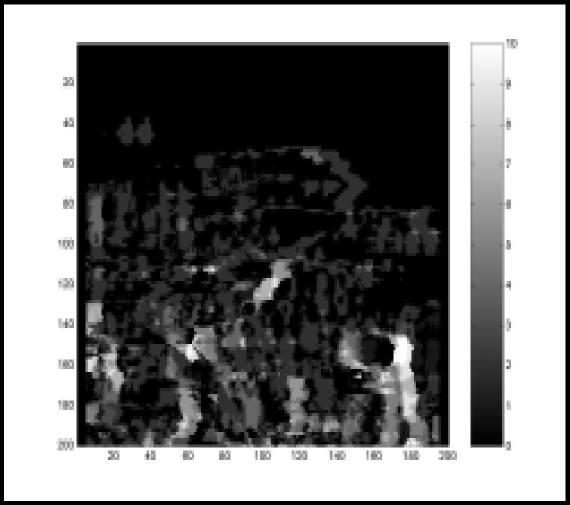


99-95%

Result-I



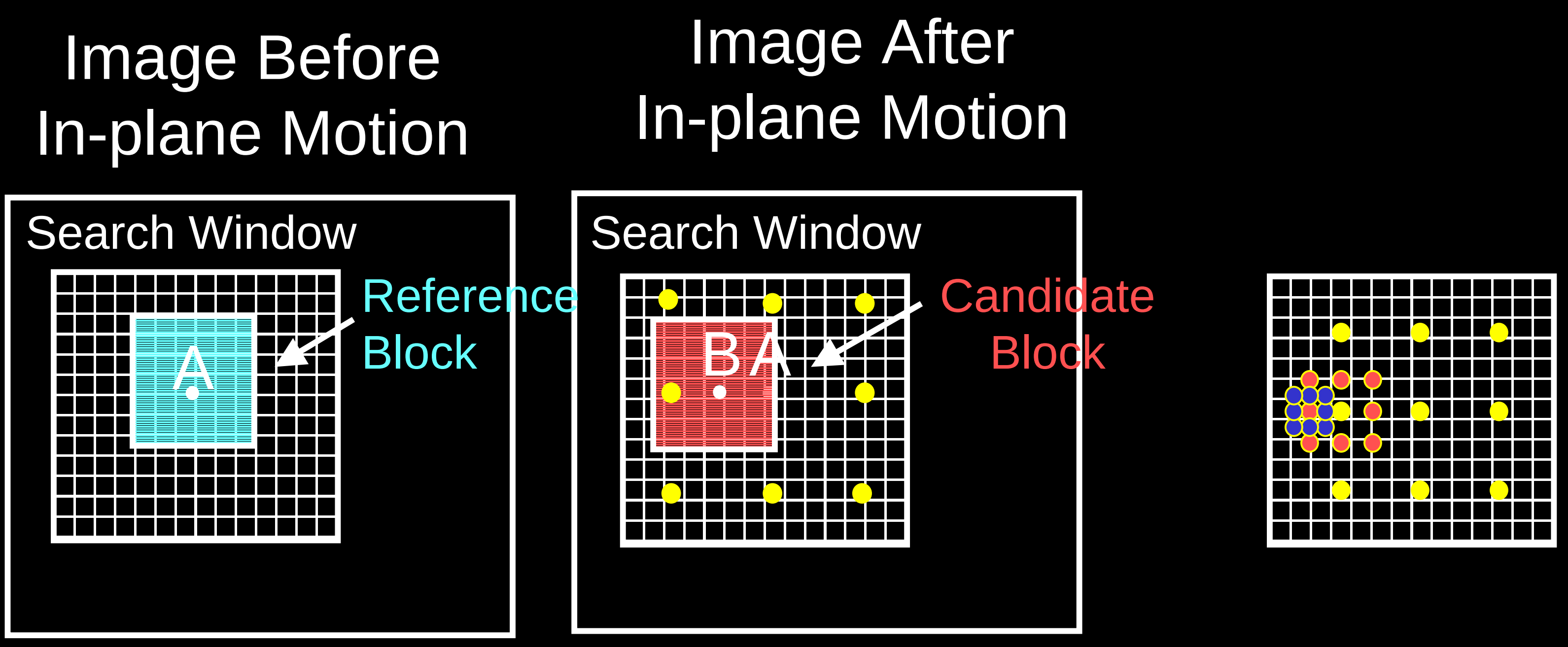
1D



2D

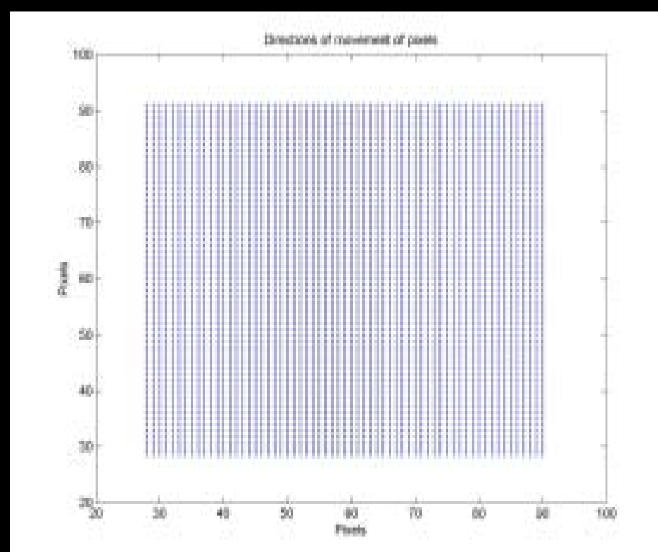
Improved Speckle Tracking
- Multi-level

- Multiple levels, 9 points estimation in each level

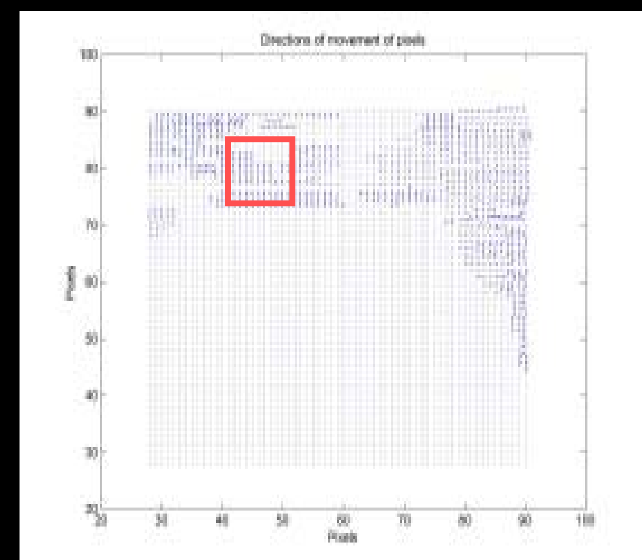


Result-II

- Comparison of full search and mult-level speckle tracking method

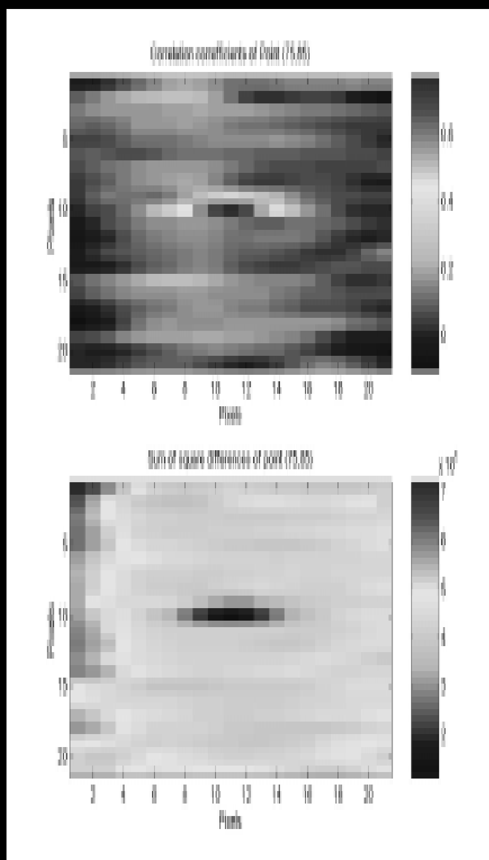


Full search



Two level

Result-II



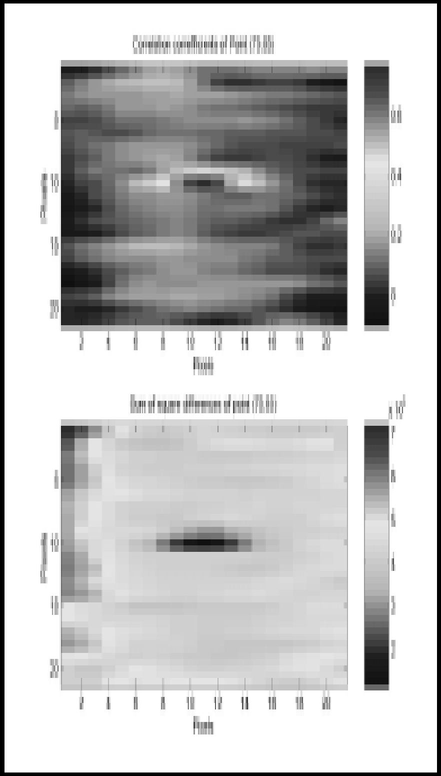
D1

475311	427026	456354
479950	(111365) 421806	423350
500169	405354	405057

C1

0.1438	0.1397	0.0552
0.1021	(0.7736) 0.1378	0.0935
0.0486	0.1856	0.1605

Result-II



D2

451723	426930	457179
451620	(111516) 427890	424554
482545	413751	411719

C2

0.1463	0.1166	0.0326
0.1353	(0.7655) 0.0969	0.0751
0.0804	0.1434	0.1265

Result-II

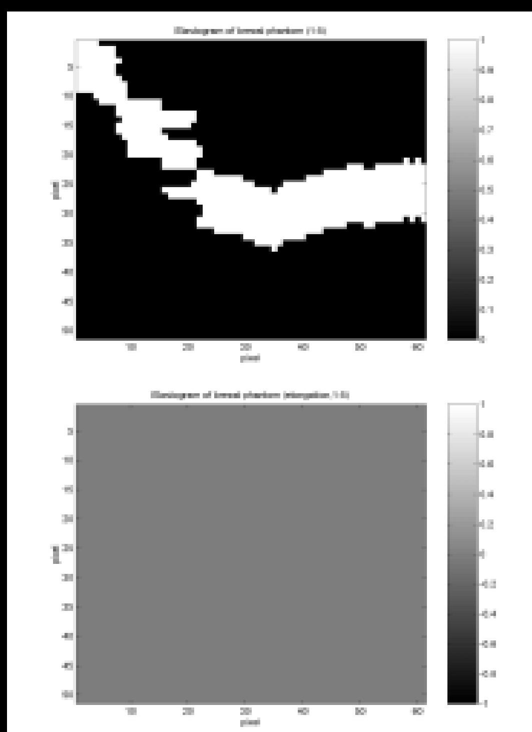
- Comparison of full search method of sum of difference and correlation coefficient

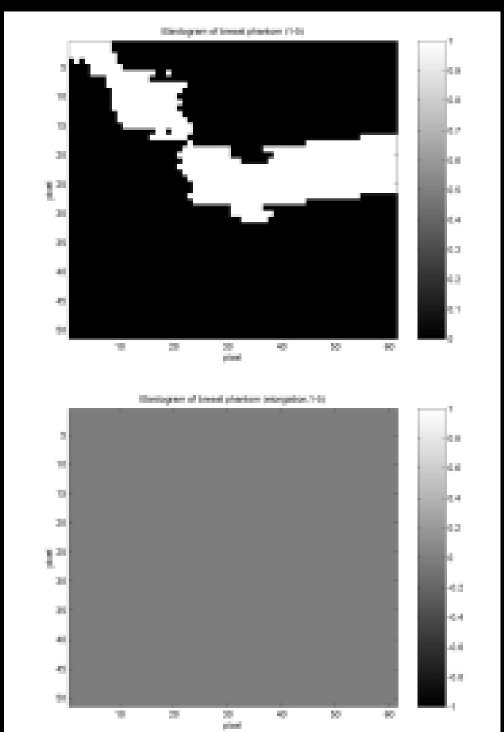
Sum of difference (1-5)

Correlation coefficient

Vertical strain

Elongation

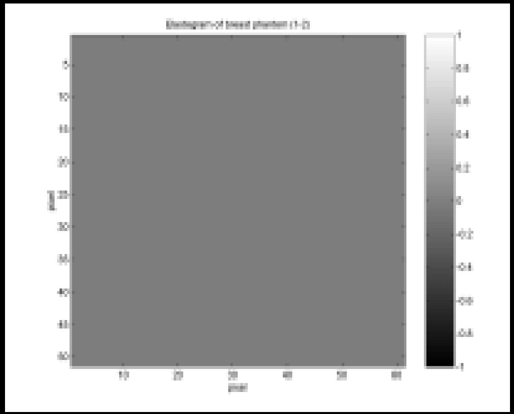




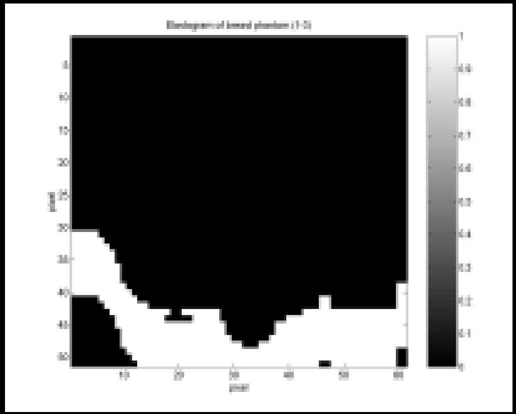
Result-II

	Sum of differences		Correlation coefficients	
	Minimal cc	Mean cc	Minimal cc	Mean cc
1-2	0.7387	0.8962	0.7387	0.8962
1-4	0.3944	0.7810	0.3944	0.7810
1-5	0.3520	0.7677	0.3520	0.7679

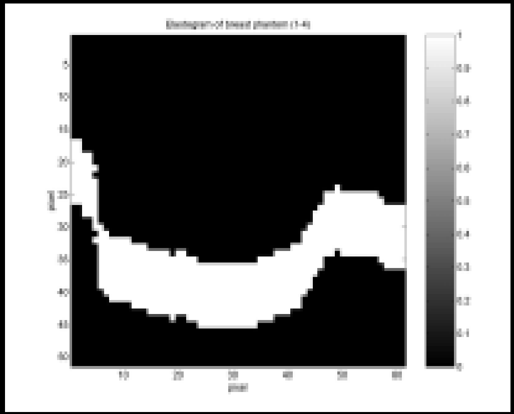
1-2



1-3



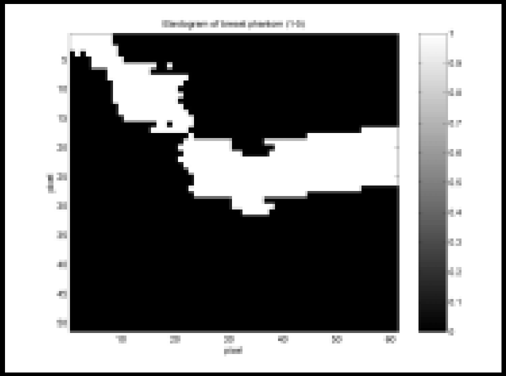
1-4

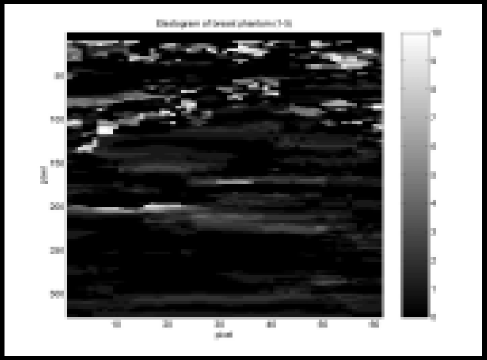


Result-II

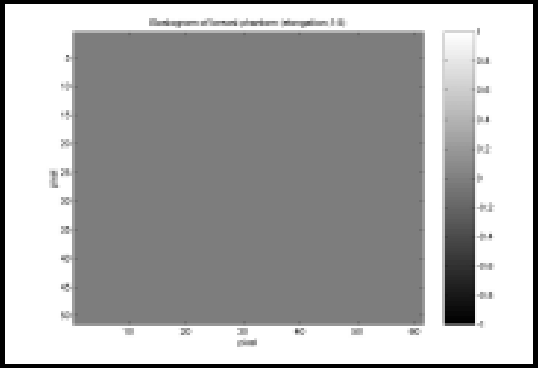
- Interpolation (1pixel --> 5 pixels)

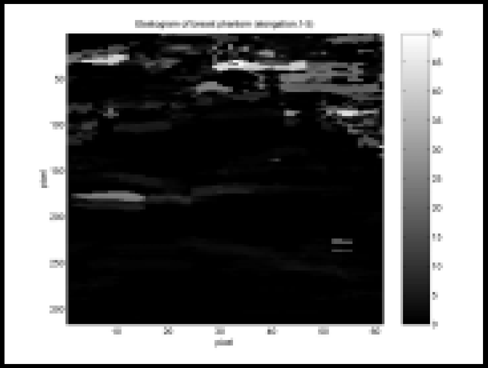
Vertical strain





Elongation

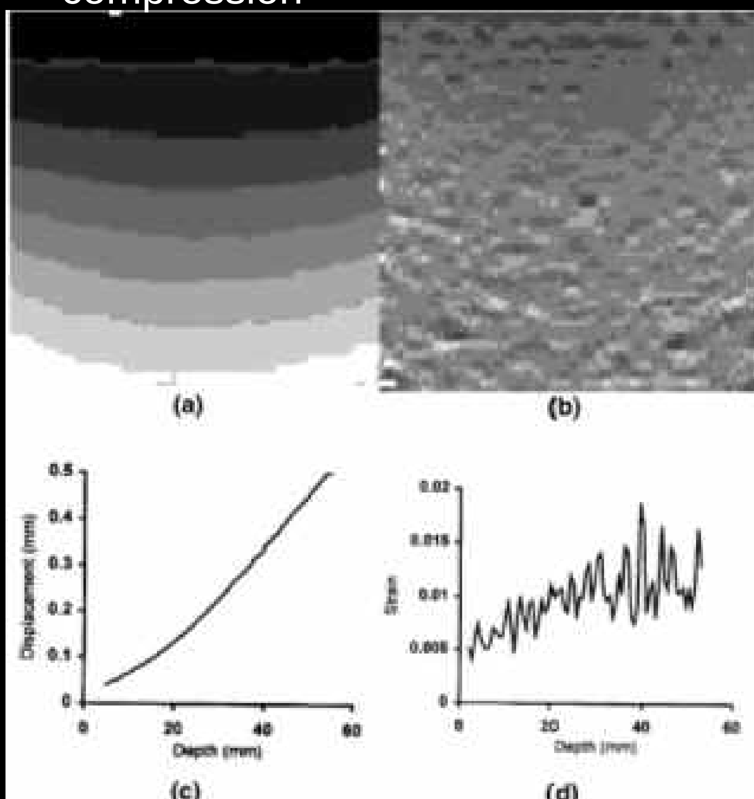




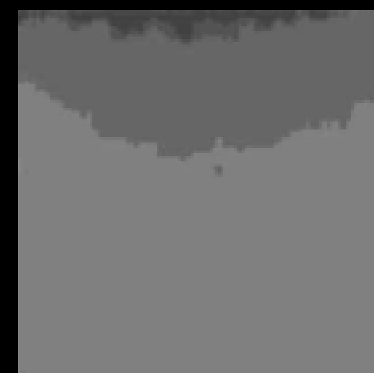
LSQSE(Least Square Strain Estimator)

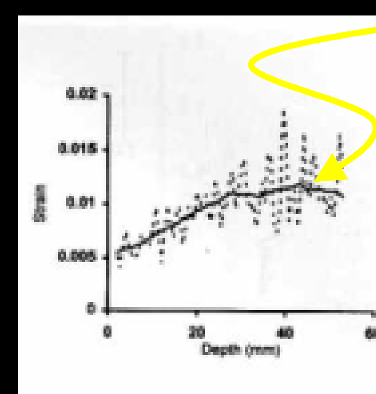
Homogeneous gel phantom From 1% applied compression

Strain Image obtained by taking the gradient of the displacement field



After LSQSE

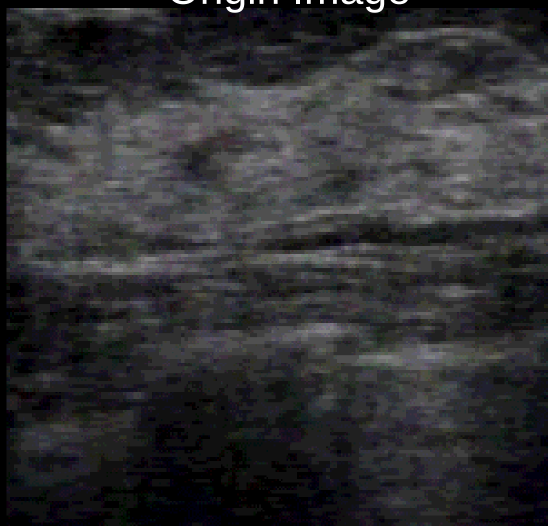




The middle column from the LSQ strain image

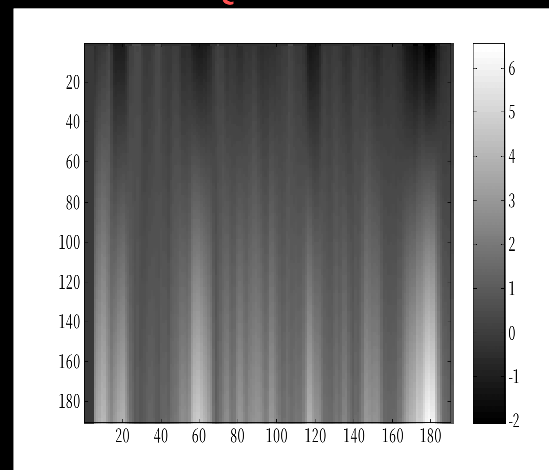
LSQSE(Least Square Strain Estimator)

Origin Image



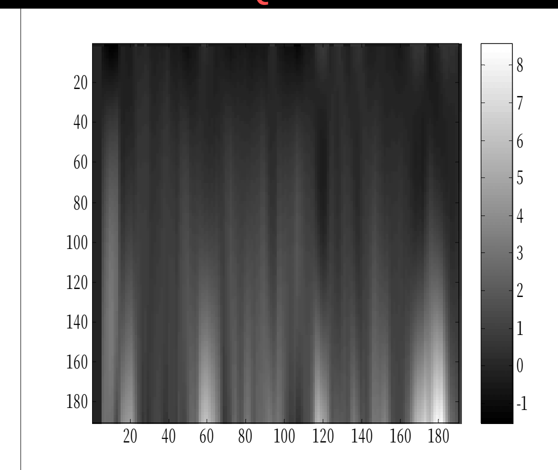
Full Search SAD Result

LSQ order 1



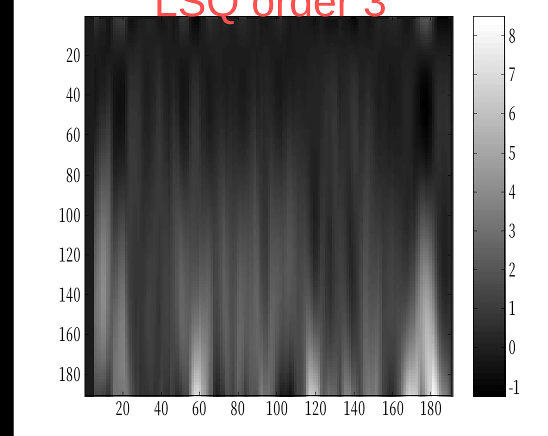
(a)

LSQ order 2



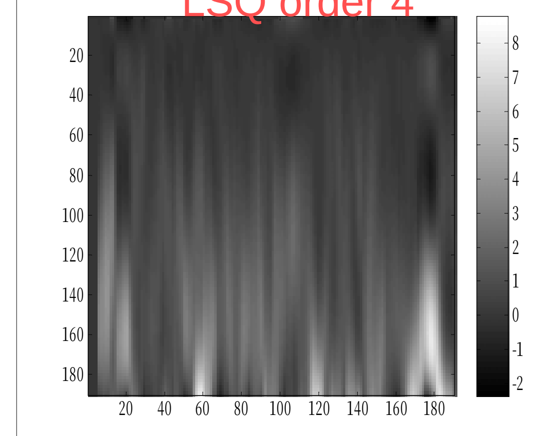
(b)

LSQ order 3



(c)

LSQ order 4



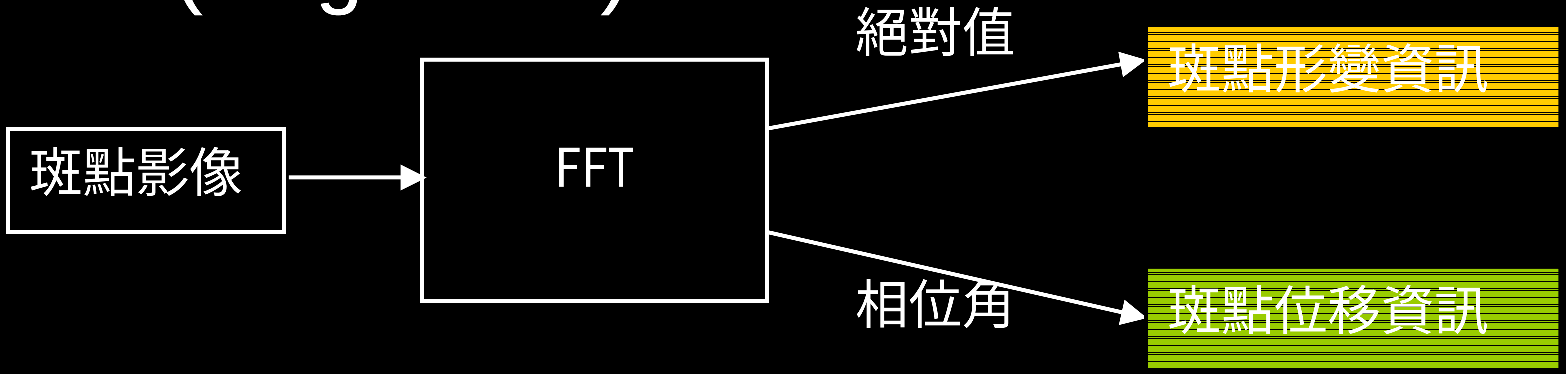
(d)

FFT-based Speckle Analysis

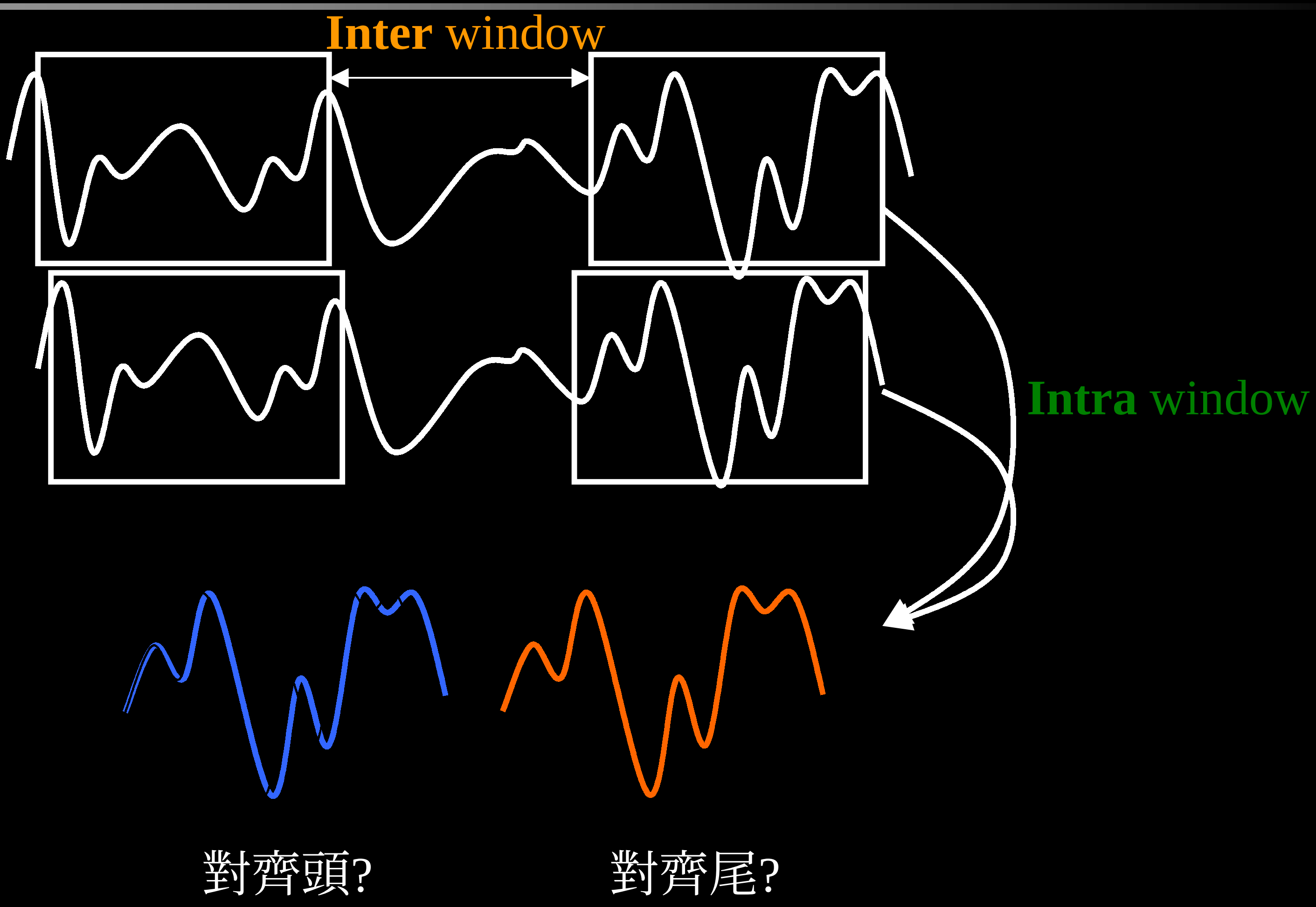
- 報告內容：
  - 原理說明—FFT之特性及優點
  - 文獻參考—Temporal Stretch Method
  - 方法與步驟
  - 結果與討論

原理說明—FFT之特性及優點

- FFT為快速演算法
- 具有 translation invariant特性 (Magnitude)

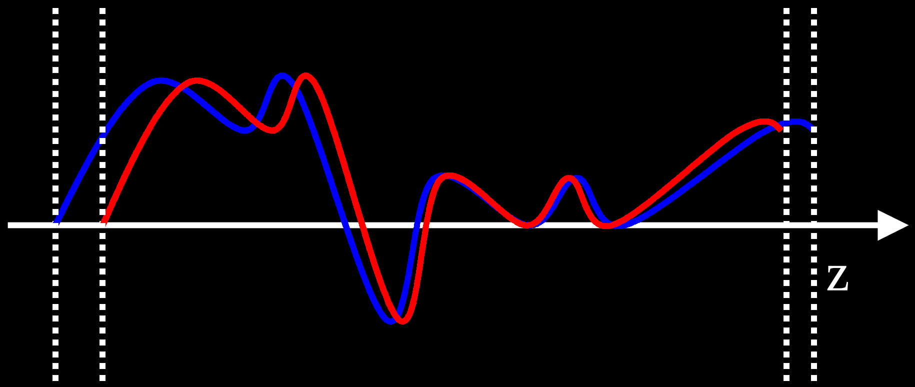


文獻參考—Temporal Stretch



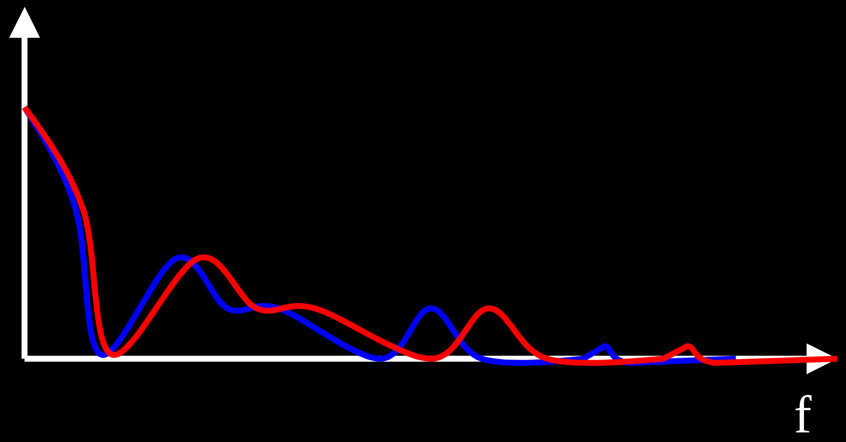
FFT-based Speckle Analysis

- 由頻域對B-mode影像進行分析
  - Z軸方向的一段組織反射信號



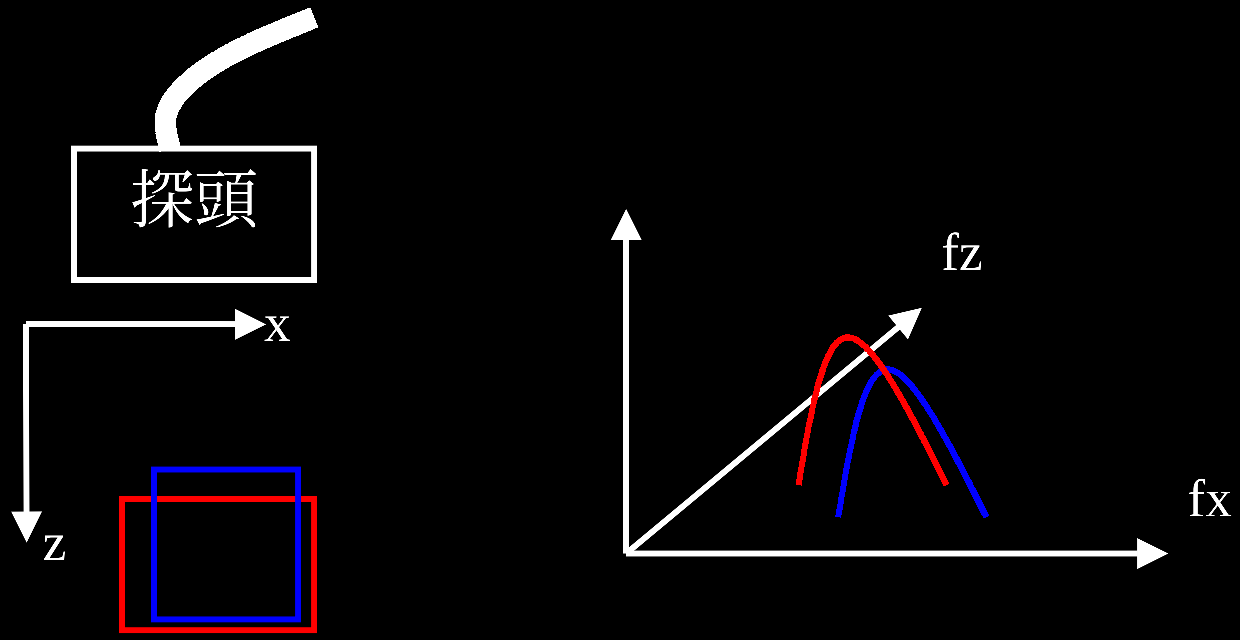
FFT-based Speckle Analysis

- 信號與系統理論 ：
  - a(z) → A(ω)
    a(kz) → A(ω/k)



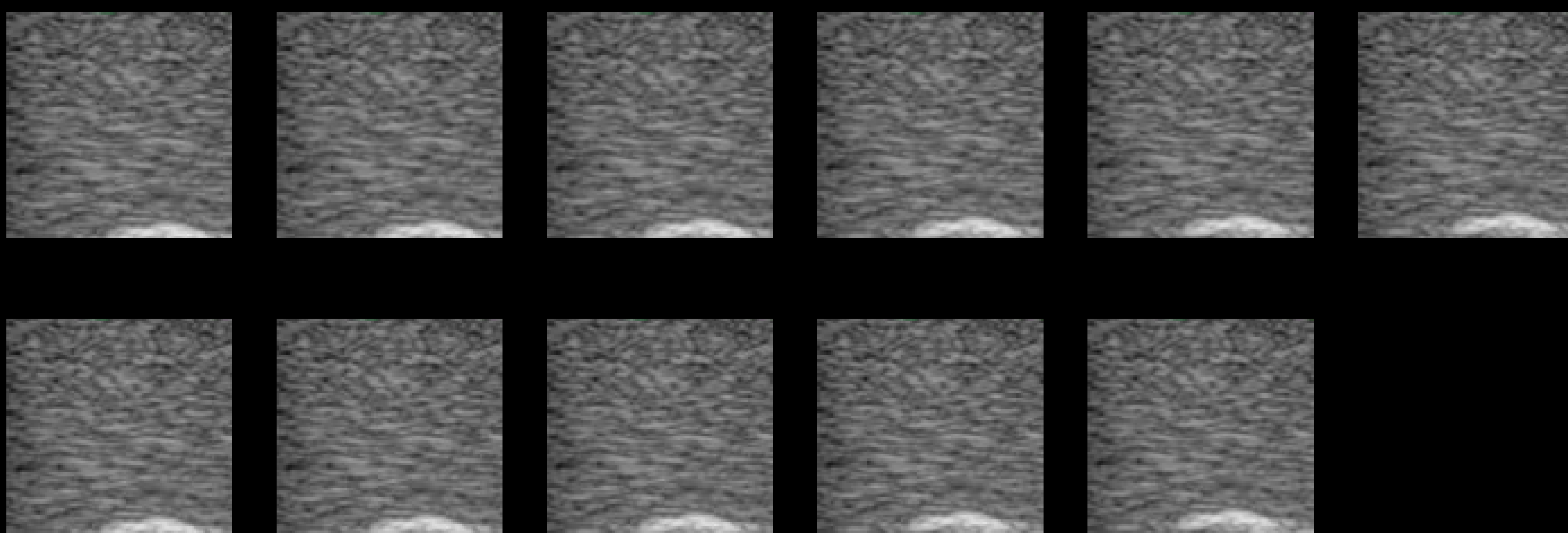
FFT-based Speckle Analysis

- 將此方法推廣至二維 ：



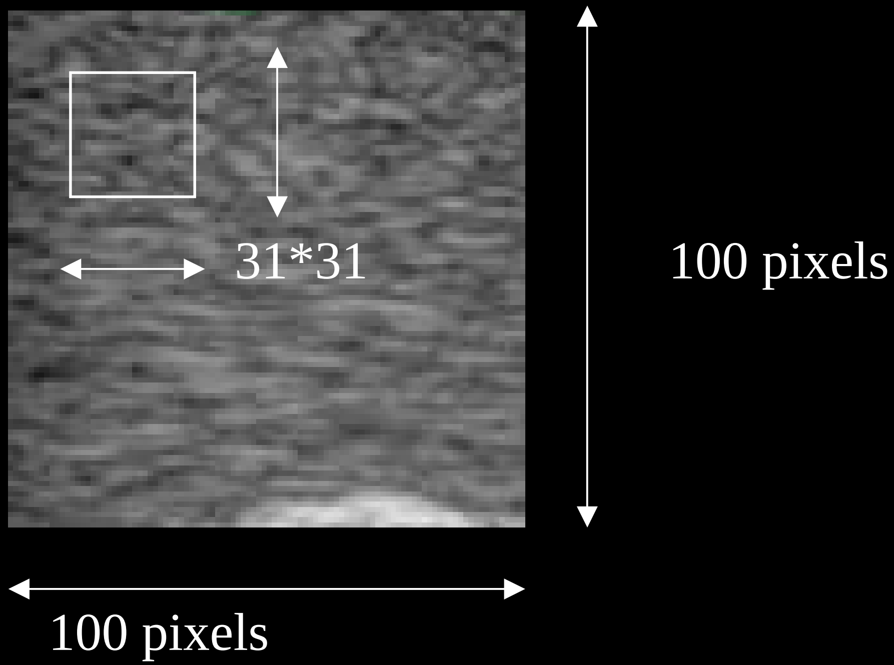
方法步驟—形變分析

- 使用一系列以photoshop進行縮放調整之speckle影像進行模擬



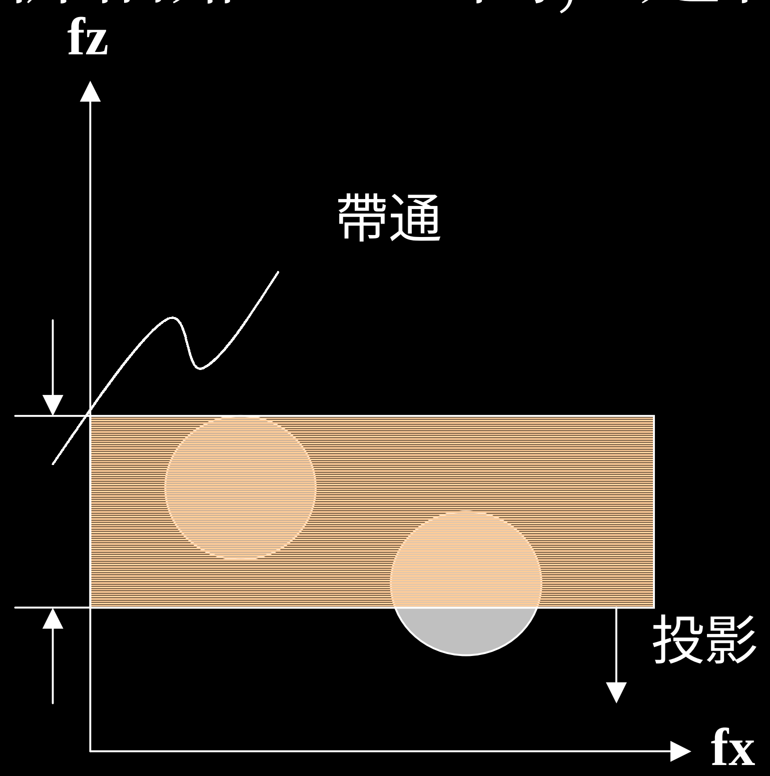
方法步驟—形變分析

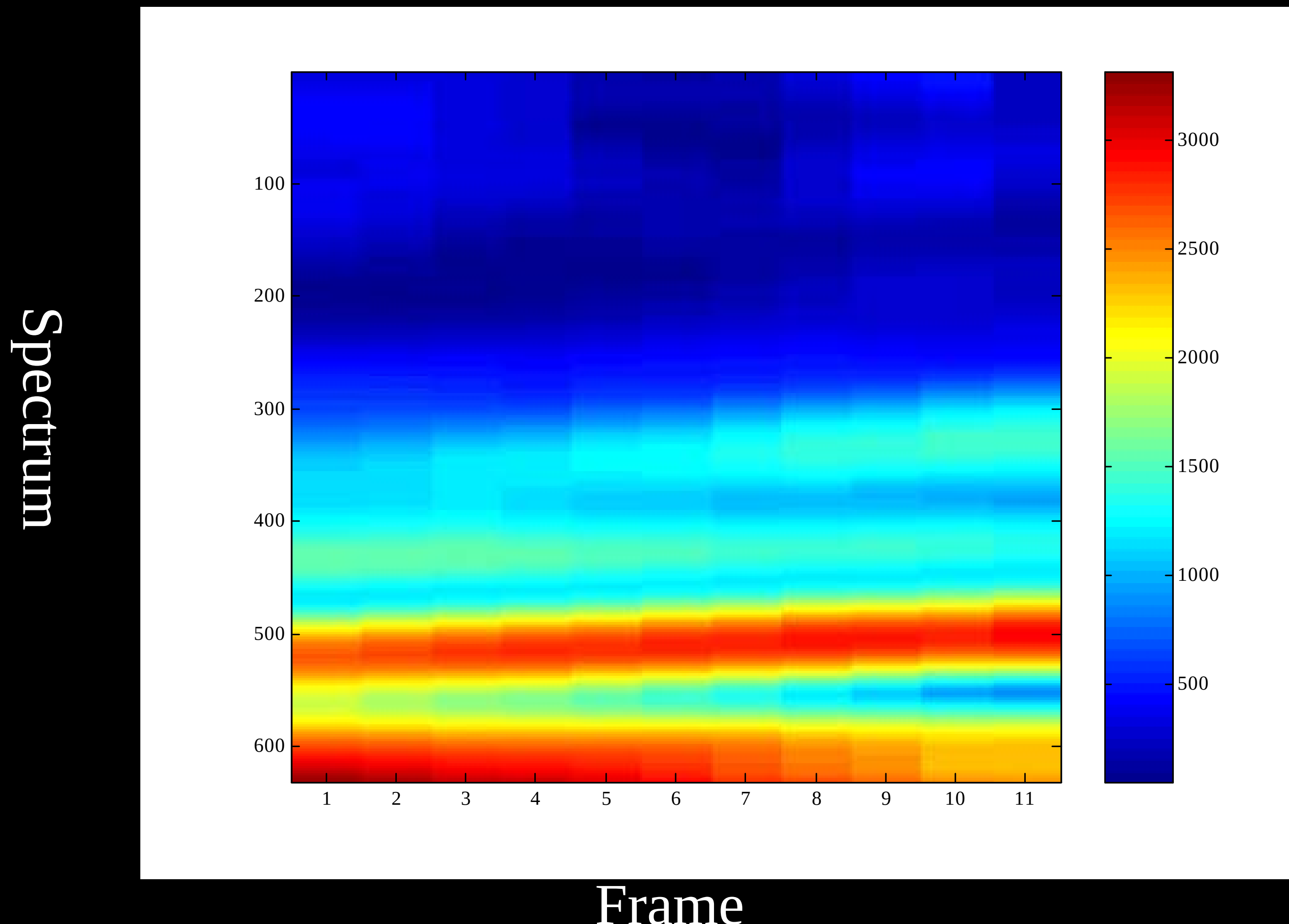
- 將每張影像取出31*31 pixels部分進行分析(不包含亮點)



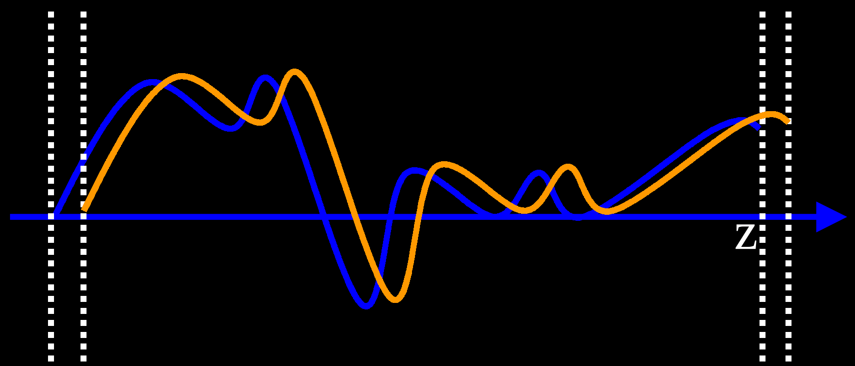
方法步驟—形變分析

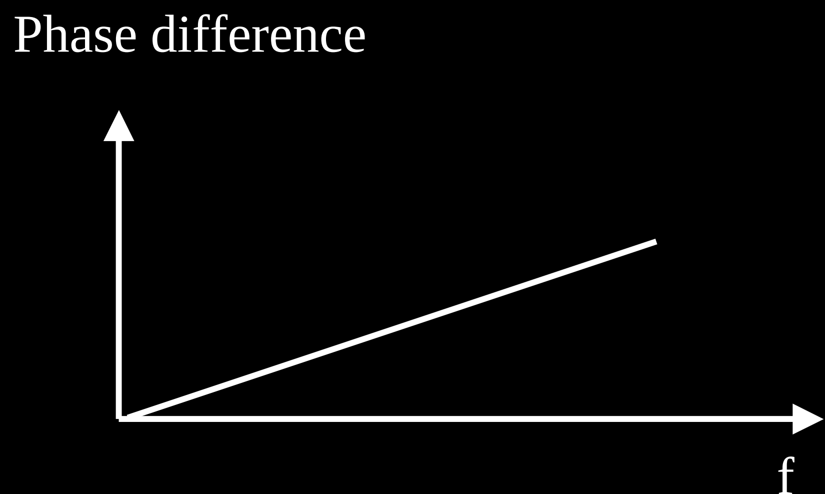
- 富利葉轉換後，保留正頻率之magnitude用來分析相鄰frame間，是否有頻率shift




Spectrum
Frame
100
200
300
400
500
600
1
2
3
4
5
6
7
8
9
10
11
3000
2500
2000
1500
1000
500

方法步驟—位移分析





$$\Delta\theta / f = 2\pi * \Delta Z$$

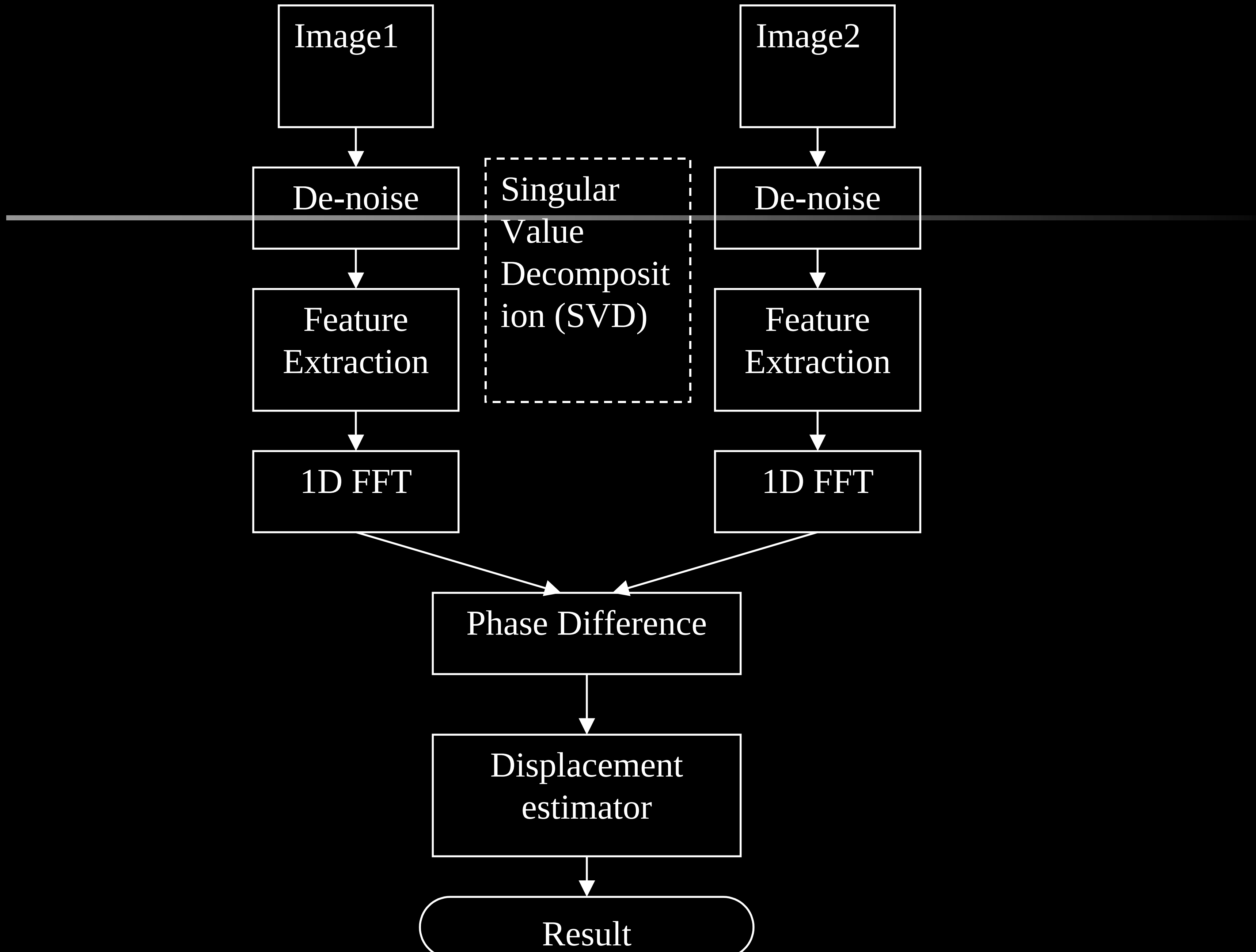


Image1
Image2
De-noise
De-noise
Singular Value Decomposition (SVD)
Feature Extraction
Feature Extraction
1D FFT
1D FFT
Phase Difference
Displacement estimator
Result

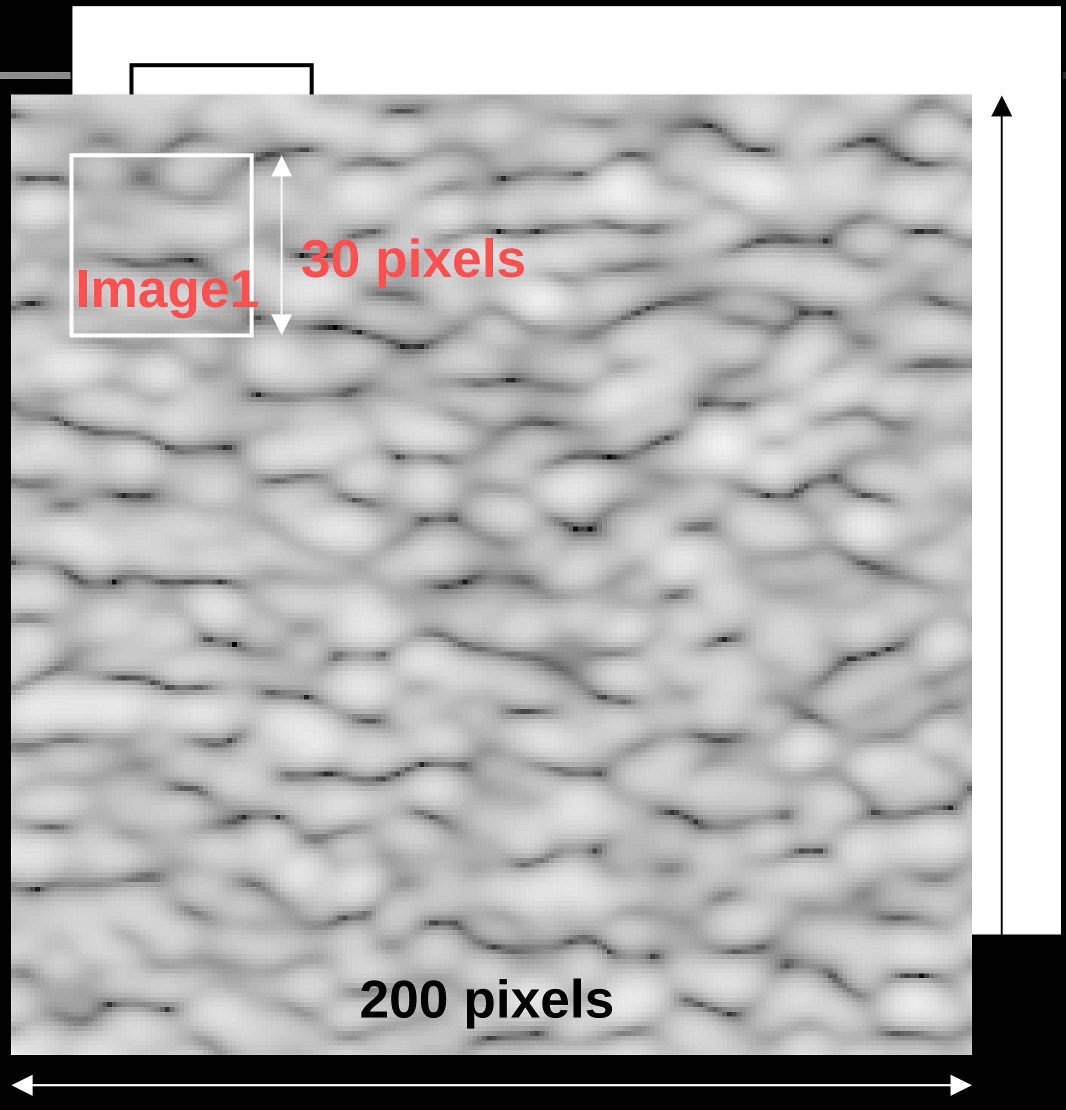
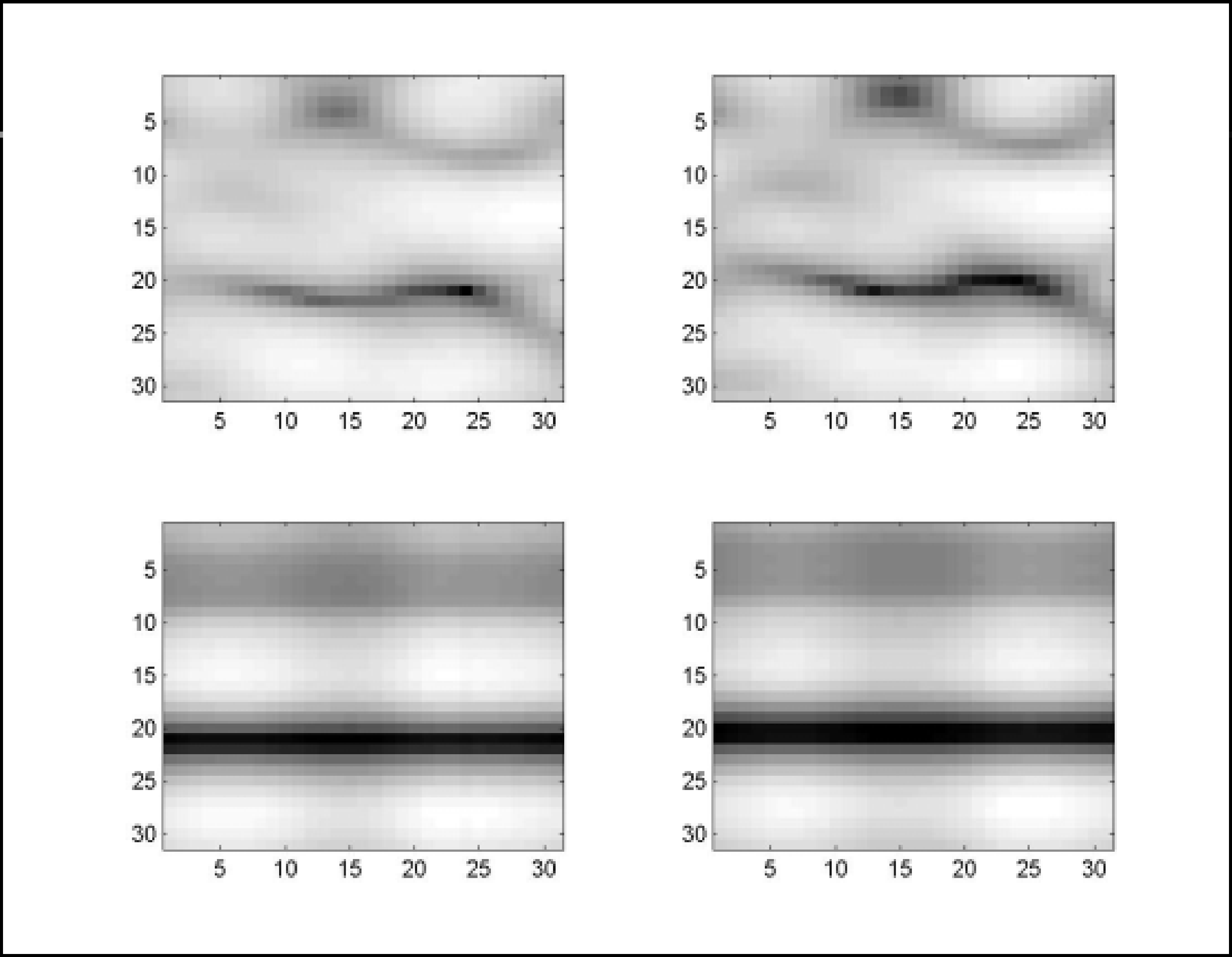
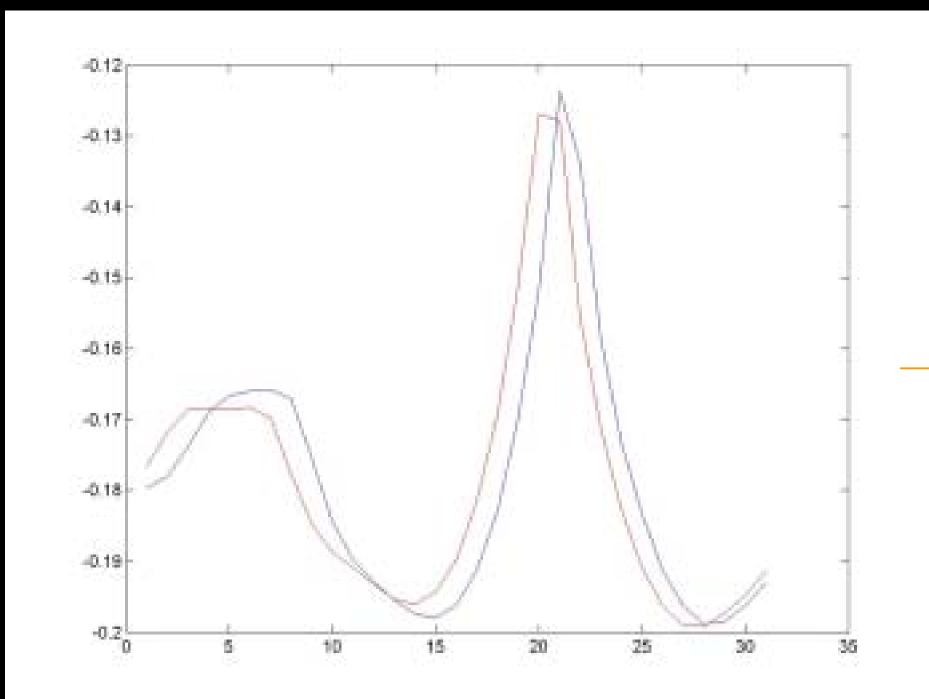
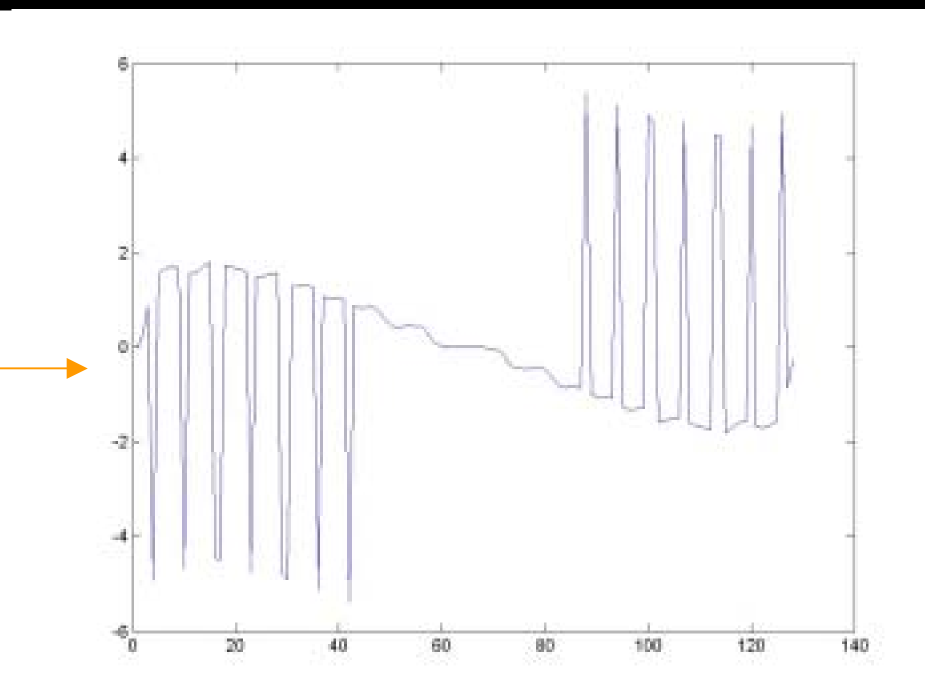


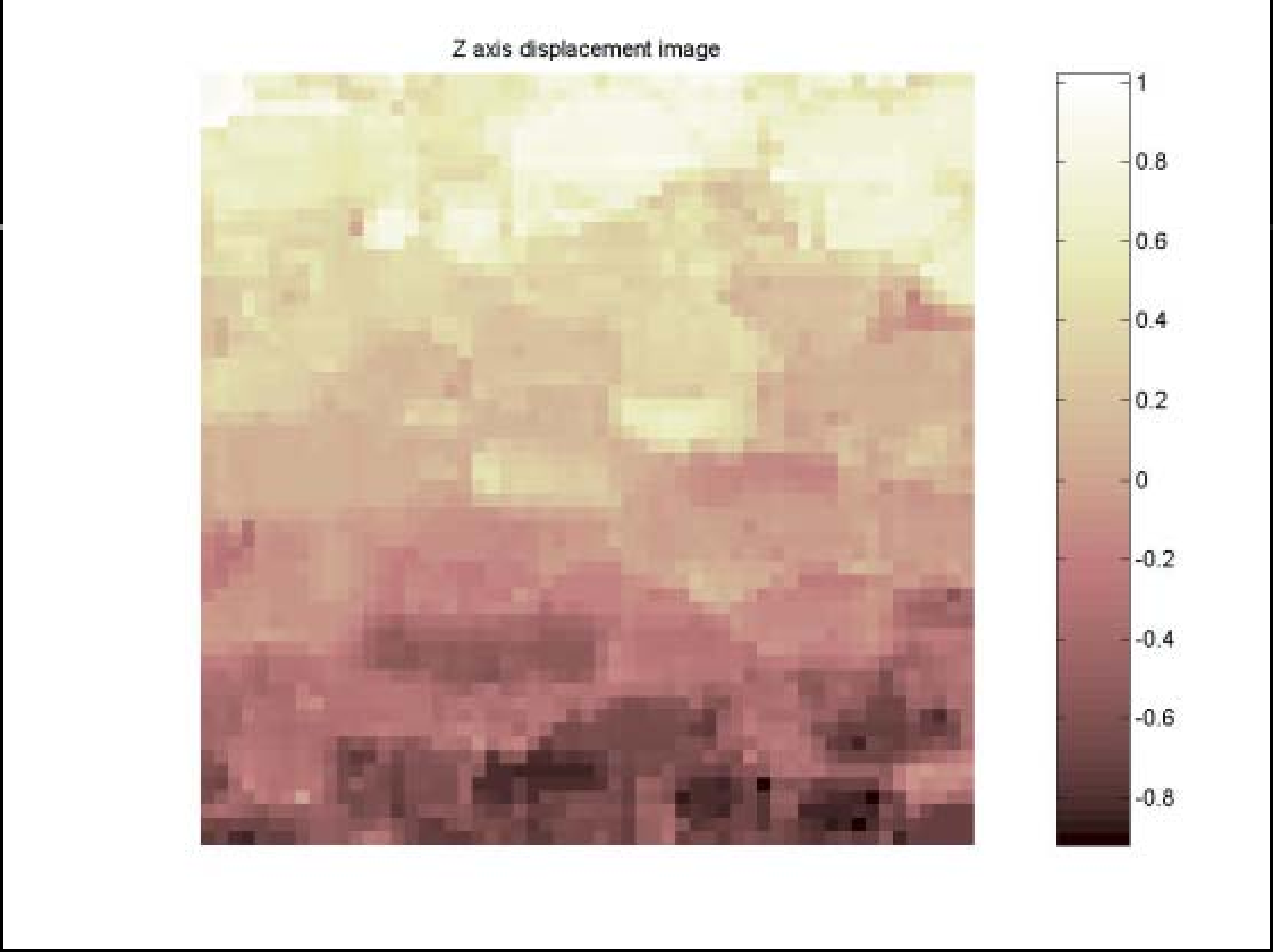
Image1
30 pixels
200 pixels

SVD 1’st eigen image



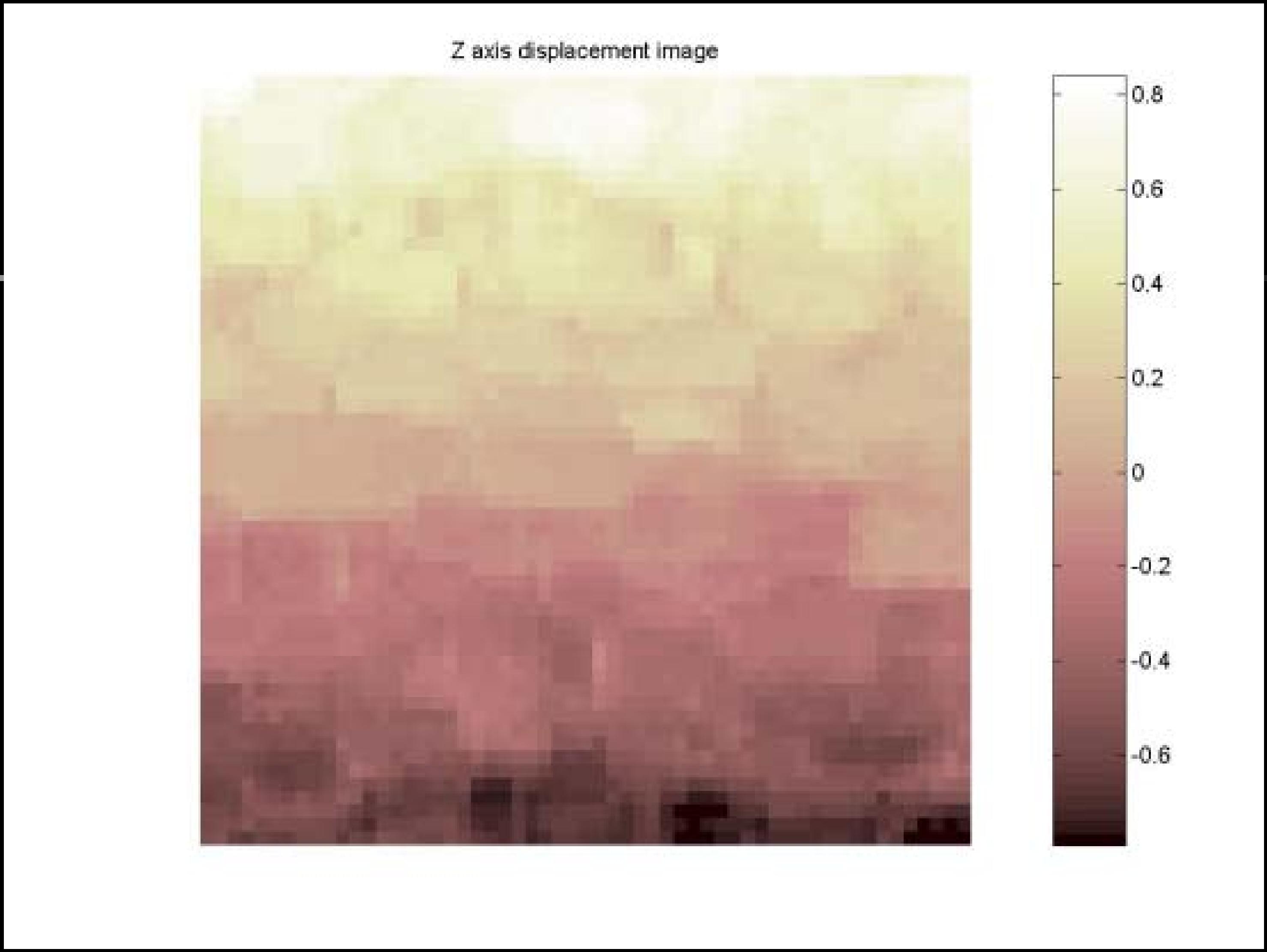

-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
-0.19
-0.2
0
5
10
15
20
25
30
35


6
4
2
0
-2
-4
-6
0
20
40
60
80
100
120
140



↓
位移量
向下為正
單位 pixel

↑以兩張相鄰strain~=1%之影像計算所得結果。

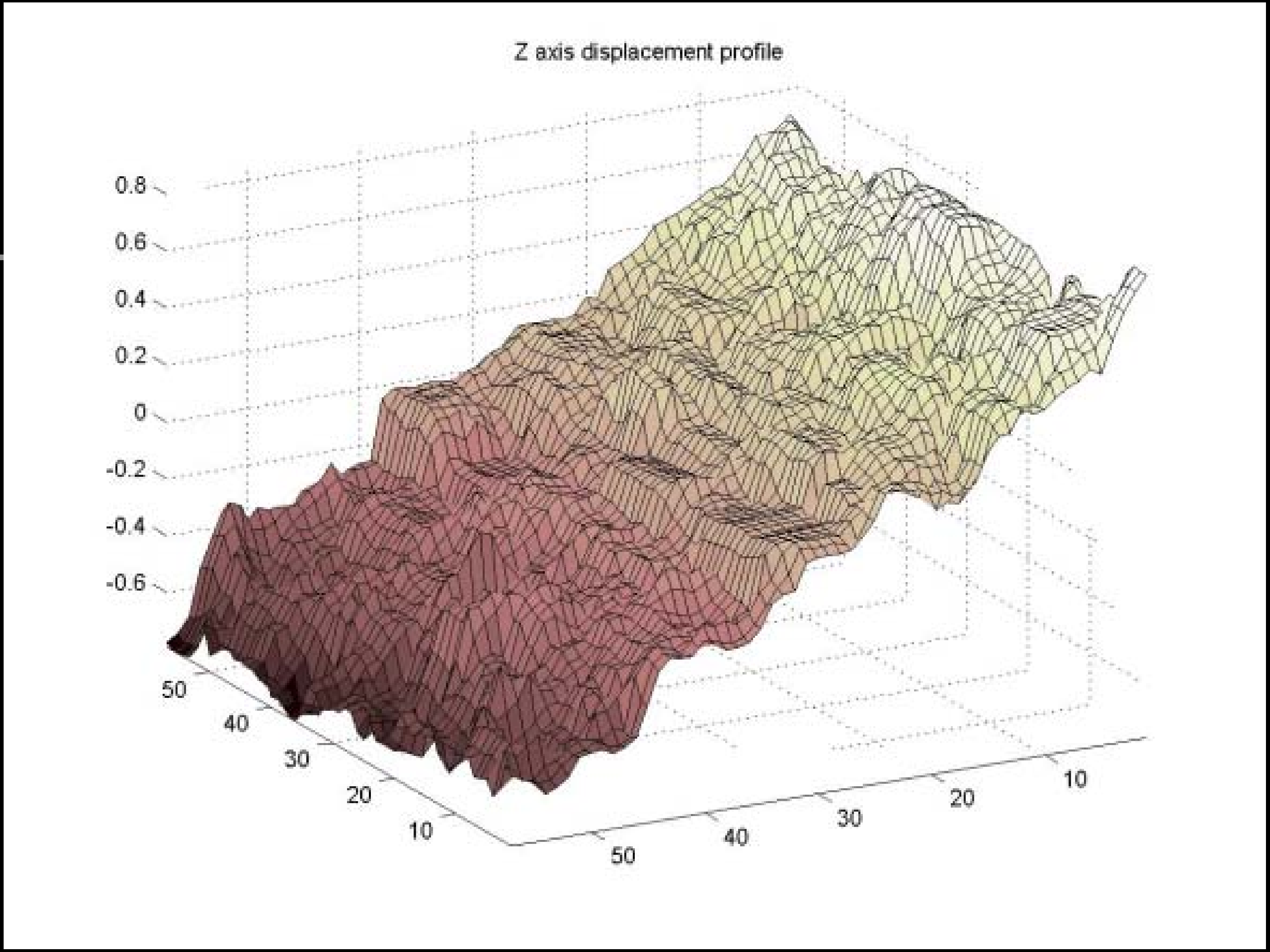


↓
位移量
向下為正
單位 pixel

↑以十一張相鄰strain~=1%之影像計算所得結果。
（十張displacement影像複合之結果）

↓

位移量
向下為正
單位 pixel



↑同上一結果（十一張相鄰像計算所得）。
以profile表示，可以看出其線性程度。

討論

- 壓縮1%的200*200模擬影像，確實可以偵測出 ±1pixel漸層變化的位移量 。
- spatial domain的filter、constrain都尚未派上用場 。
- strain是位移量的微分 。
- 如果有簡便之類似運算可代替SVD，將比傳統speckle tracking大幅節省運算量。

Discussion

- 1D method has higher sensitivity, but also higher noise (lower correlation coefficients).
- More diffuse distribution of strain signal than 2D method
- 2D method has higher precision rate (high correlation coefficients) and best X direction displacement estimate.
- Band like strain signals were estimated for simulation and phantom images, the cause may be due to quantitative error (accumulated of tiny strain relived at the similar row)

Discussion

- For clinical breast tumor images, 1D and 2D method could detect the strain both.
- Multiple level speckle tracking method would produce obvious error and is not suitable for ultrasonic strain estimation.
- Full search sum of difference method has near similar high precision rate as the correlation coefficients method
- Interpolation could increase the sensitivity but also the noise, long time period was used in calculation.

Future work

- Try the least square strain estimator proposed by Ophir group for smoothing the images(denoise?) in 1D (1 method?)
- Applying pyramid method for fasting the calculating speed of sum of difference method.
- Improving the interpolation method for reducing the noise.

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