Surface motion reconstruction for a DIET system

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Introduction

- **Breast cancer** has second highest mortality rate of all cancers for women worldwide. In New Zealand it is number one.

- **Mammography** is the standard for breast cancer screening
  - discomfort to patients and health risk (exposure to radiation)
  - interpretation of images is subjective → misdiagnosis, false positives

- **Digital Image-based Elasto-Tomography (DIET)** is an emerging low cost technology for non-invasive breast cancer screening
  - digital imaging of actuated breast to determine tissue motion
  - 3D internal tissue stiffness reconstruction (finite element method)
  - Regions of high stiffness suggest cancer

- **Problem:** Requires very accurate tracking to a high resolution at 100Hz
- Solution: Digital cameras/strobocope and tracking of large numbers of artificially placed coloured marks.

DIET system overview

- The DIET system is broken down into 4 fundamental steps:

(1) Actuation → (2) Image Capture → (3) Motion Tracking and measurement → (4) Tissue stiffness reconstruction

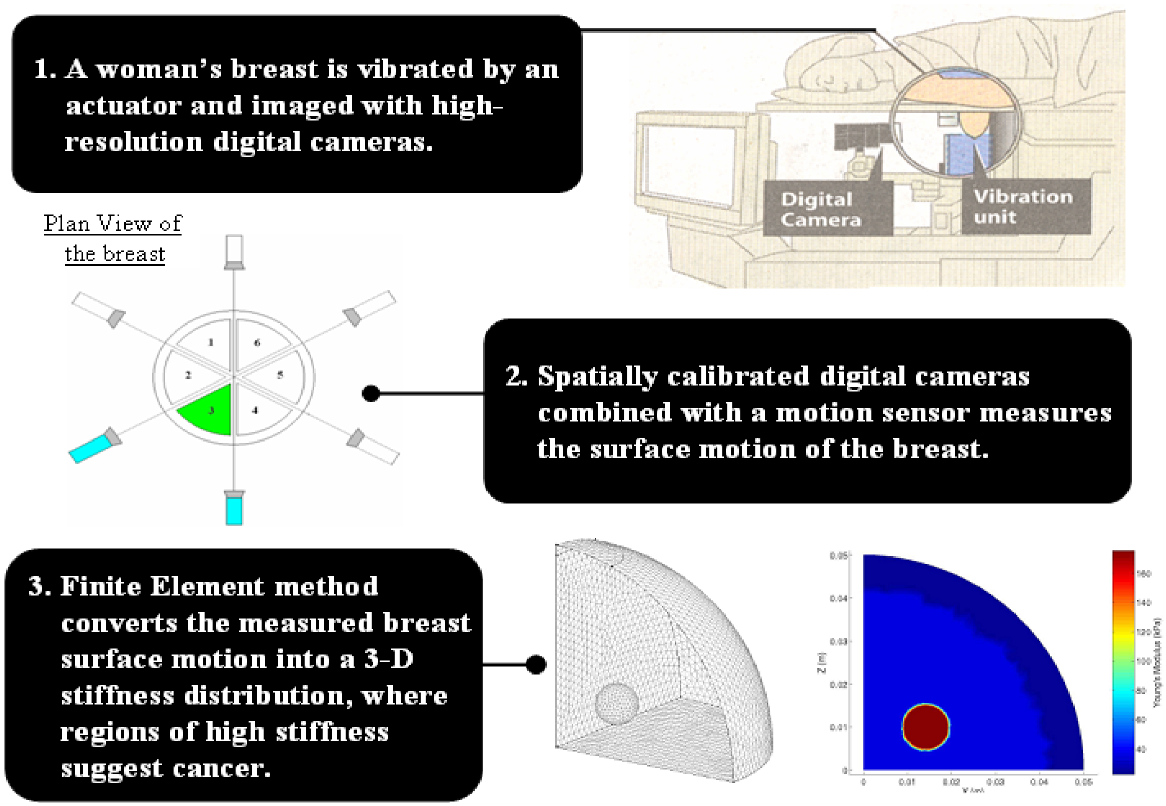

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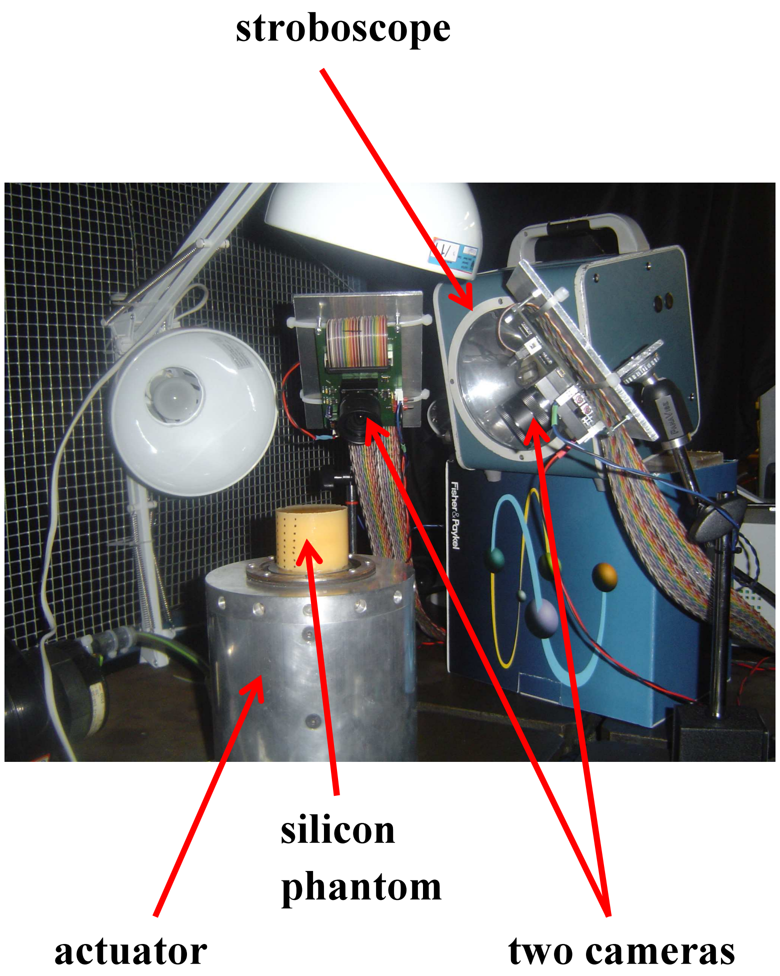
Image capture apparatus



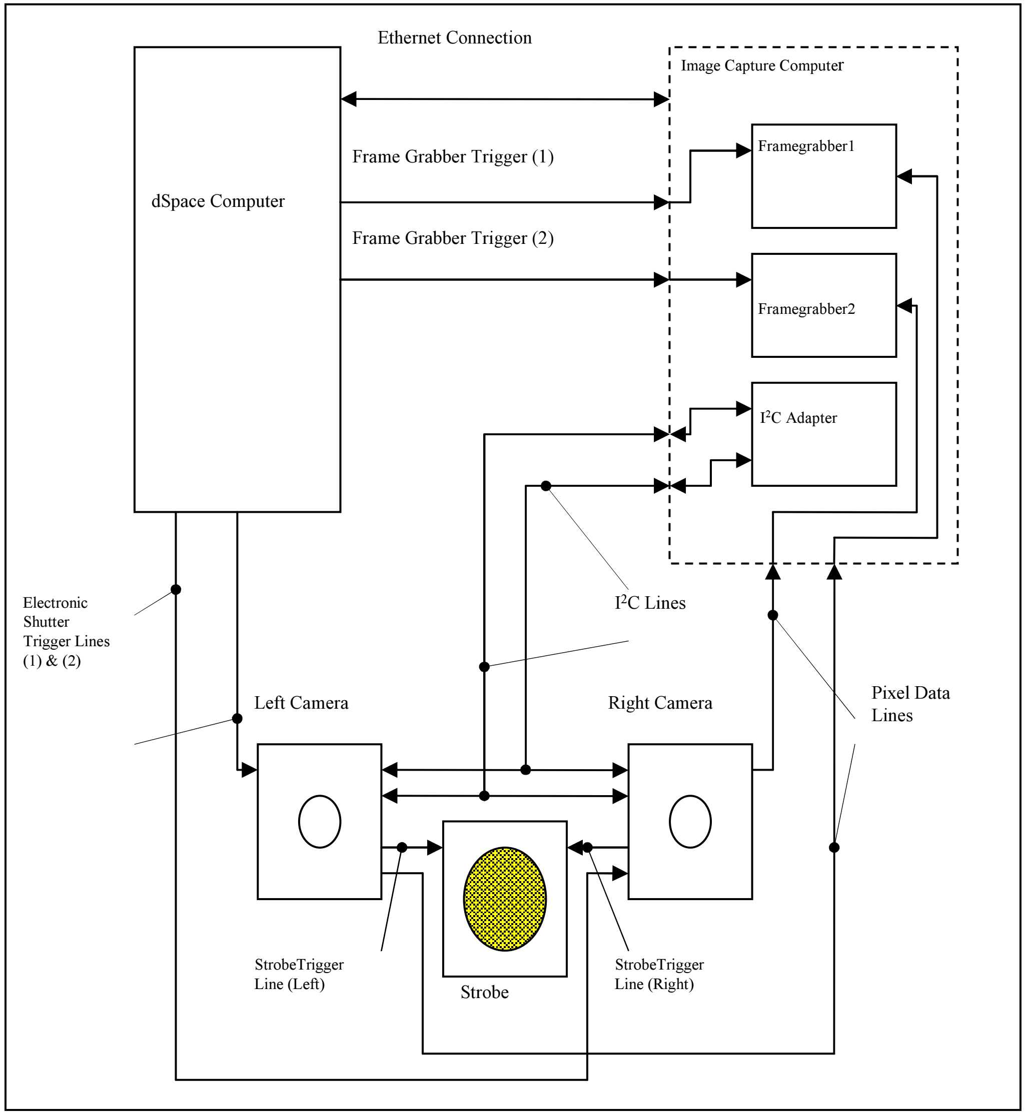
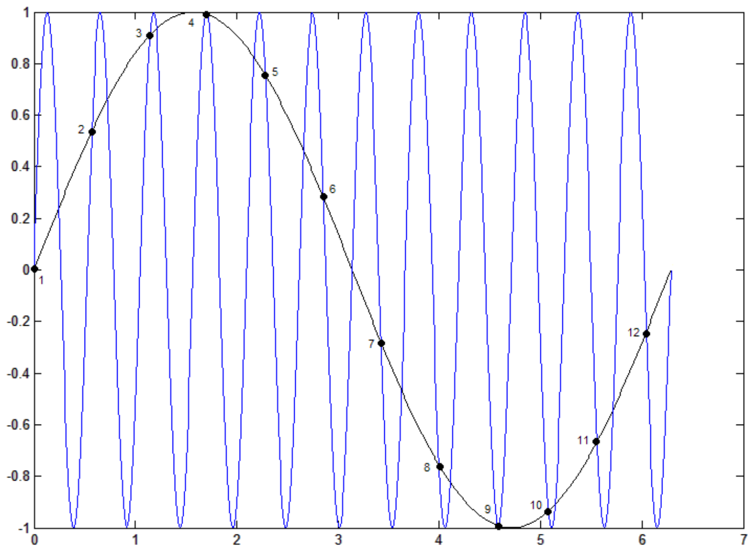


Image capture - overview

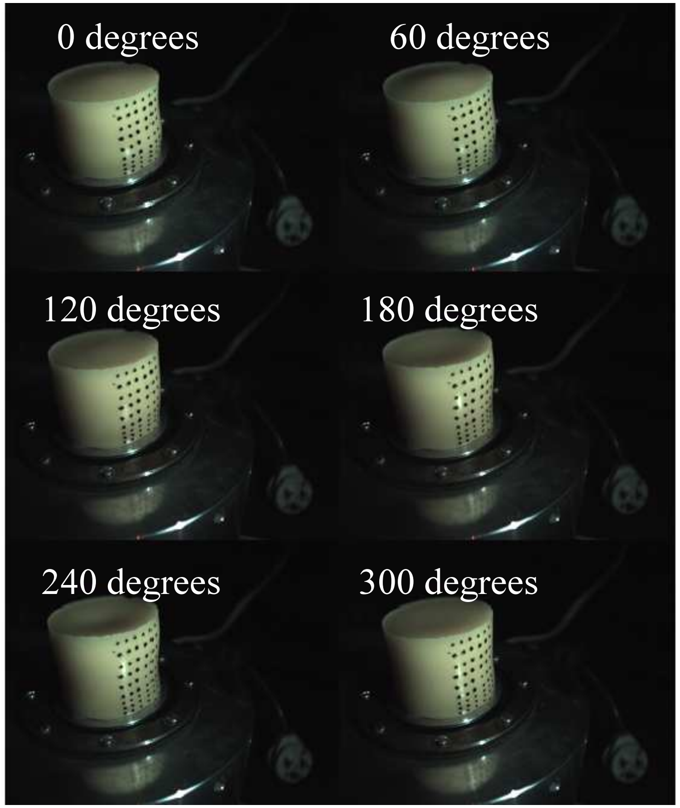
- The frame rate of cameras at 1-2 Megapixels (CMOS imaging cameras and standard consumer Canon Powershot G5 cameras) and is approximately 18fps
- To overcome this insufficient frame rate the breast is strobed at specific points in its motion



- In practice time between captured images 1-10 seconds ➔ 100-1000 cycles between images

Image results - example

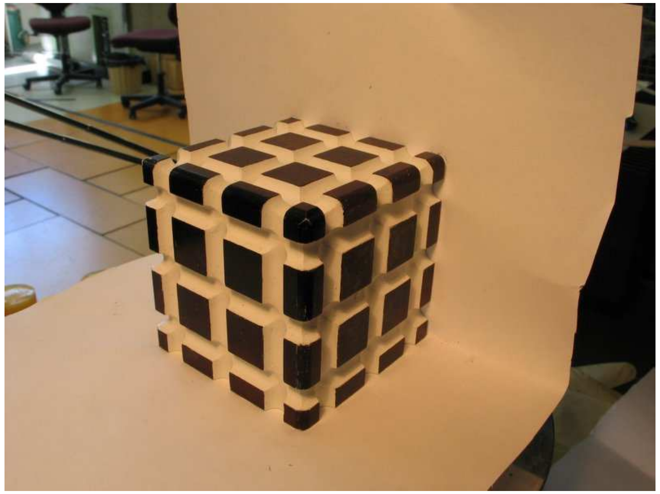
- Silicon phantom 50mm diameter, 40mm height
- Actuation frequency = 50-100Hz,
- Amplitude =0.5-1.2 mm



- Six images shown (60 degrees)
- 54 black dots
- 36 images = 10 degrees phase lag

3D motion reconstruction – Camera calibration

- Digital Camera = perspective projection pinhole camera
- **X**=(X,Y,Z,W), **u**=(u,v,w) ➔ $\lambda \mathbf{u} = K[RT]X$
- K = intrinsic camera parameters, T = 3D translation of camera, R= 3D rotation of camera
- In R^3 and R^2, $\left(\frac{X}{W},\frac{Y}{W},\frac{Z}{W}\right) \rightarrow \left(\frac{u}{w},\frac{v}{w}\right)$
- **<u>If K, T and R are known</u> ➔ camera is calibrated**



These are what the camera "sees"

- Previous method (commonly used)
  - calibration cube, faces and locations of squares automatically found
  - known 3D positions used to calibrate camera
  - requires at least 3 images from different camera angles → computationally intensive

- Camera calibration

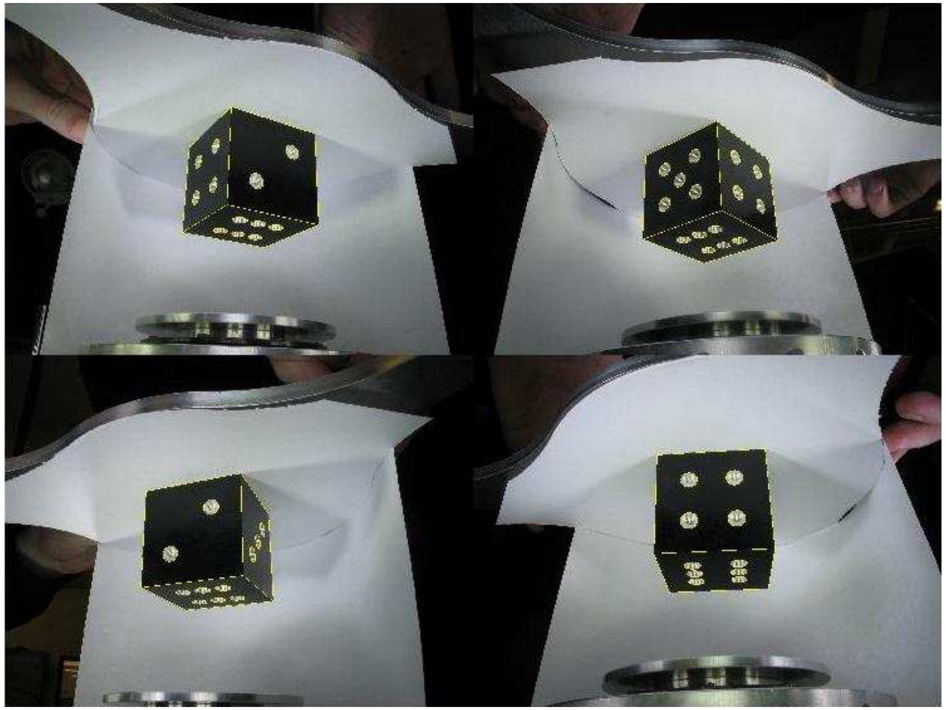
- **New method**

  - precisely machined 54mm^3 anodised aluminium die.

  - point locations on silhouette of cube and centroids of the circular "dots" known

  - perspective view ➔dots becomes ellipses, but centroid is projectively invariant

  - dots uniquely identify which faces are visible



- Calibration is fully automatic, fast and **<u>only requires a single image of cube</u>**

- Calibration error (reprojection error, projecting known world points onto image),

  ➔ 0.3-0.5 pixels, for 2 mega pixels

  ➔ ~0.1 mm in motion

Feature tracking using invariant signatures

- Assume motion is locally Euclidean (translation+rotation)
- Form a Euclidean signature space where motion is invariant to translation and rotation.

- Characterize image space by point triples that are nearby each other.
- Let **u** in E^2 be image points. Denote Euclidean distance metric by d(;). Define signature function $f:(E^2)^{(\times 3)} \mapsto R^3$ by:

$$f:(\mathbf{u}^1,\mathbf{u}^2,\mathbf{u}^3) \mapsto (d(\mathbf{u}^2,\mathbf{u}^1), d(\mathbf{u}^3,\mathbf{u}^1), d(\mathbf{u}^3,\mathbf{u}^2))$$

- $\mathbf{u}^1$ = red point, $\mathbf{u}^2$ = closest blue point, $\mathbf{u}^3$ = closest green point,

- **Signature space is defined on red points**

- **Red points are placed at significantly smaller density**

Tracking procedure

1) Extract all red, green, and blue point locations from images

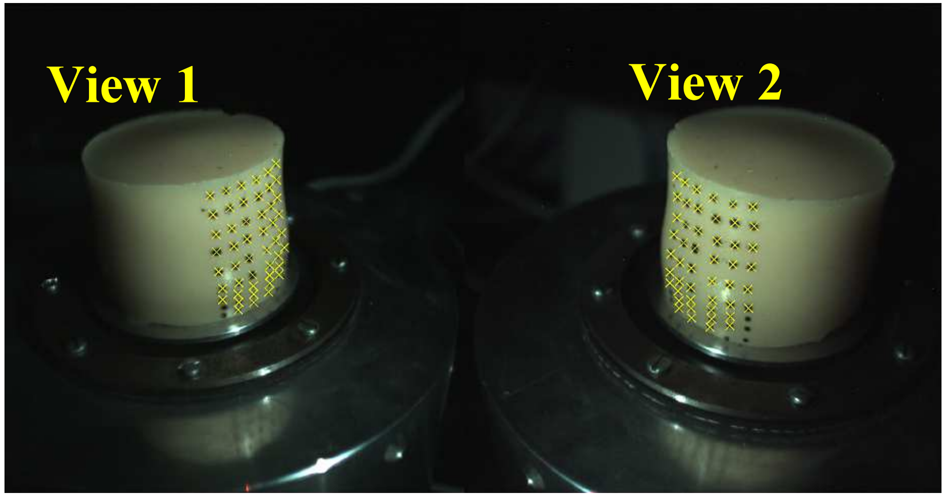
2) Find nearest blue and green neighbours to each red point to form the point triples

3) Compute motion invariant signature for each red point

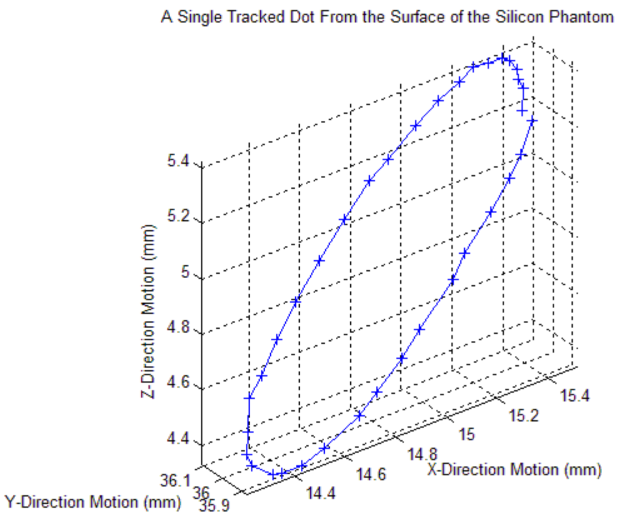
4) Match triples by matching their signatures in signature space
   - discard any matched red points that are > upper bound on expected motion

5) Match remaining unmatched points by interpolating motion between matched points

Feature correspondence between two views



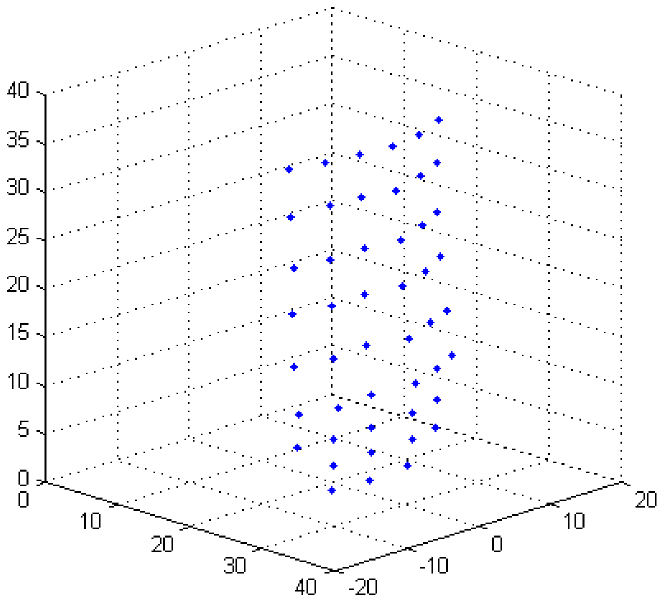
Example of Tracked point

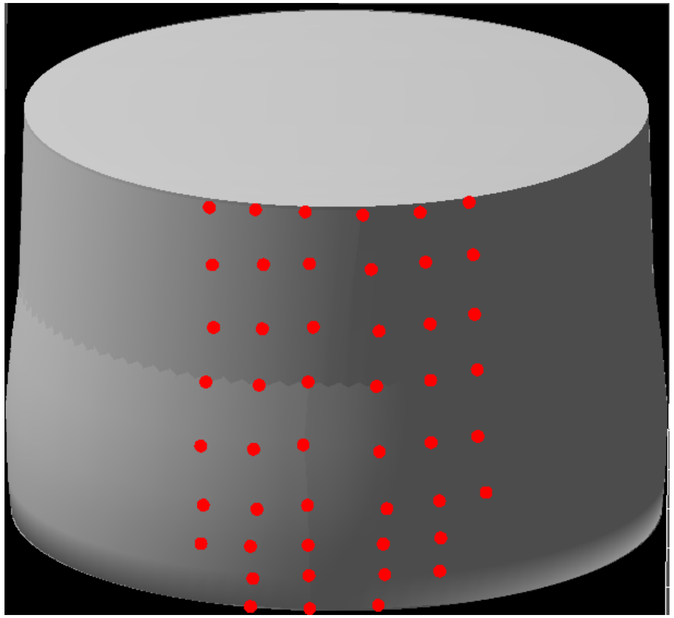


- Use standard epipolar constraint to get initial matches
- Fit least squares ellipses to tracked points
- Rule out non-corresponding points using fact that ellipses go to ellipses
- For more details see paper!

Example of surface reconstruction

surface reconstruction (snap shot during actuator cycle)





Virtual silicon phantom constructed by symmetry – agrees with visual images throughout actuation

Summary of motion reconstruction

Step 1: Synchronising images between cameras

Step 2: Tracking the motion of feature points in individual camera frames

Step 3: Calibrating the cameras and finding correspondences between tracked sequences of points between cameras (ellipse matching)

Step 4: Use camera calibration and point correspondences to find 3D location of each point

Step 5: Fit surface through 3D points for each frame, and thus obtain a moving surface through the actuation sequence.

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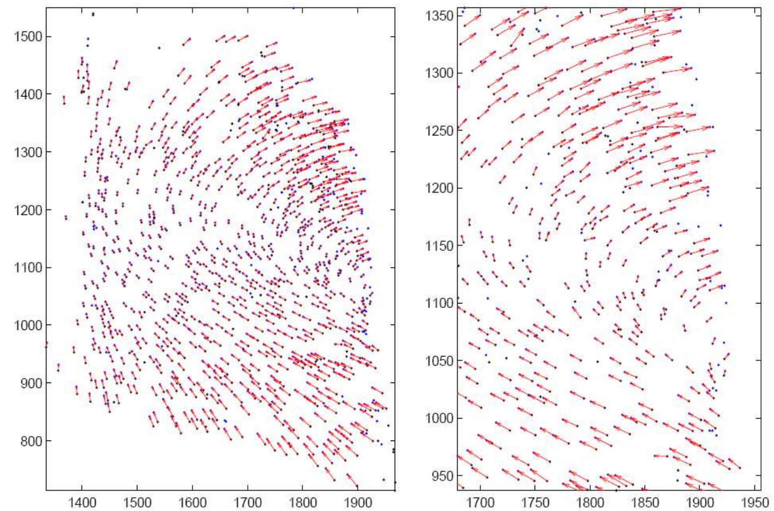
Gel Phantom simulation

Colours and points successfully detected

- ~750 coloured fiducial marks
- 100 red, 300 blue, 350 green
- Frequency=50Hz, 1mm peak to peak
- 20 images (18 degrees of phase)

- 90% of fiducial marks tracked successfully by point tracking method (see paper)
- Based on calibration accuracy, points are tracked within 1-2% of the magnitude of the silicon response (<0.1 mm)

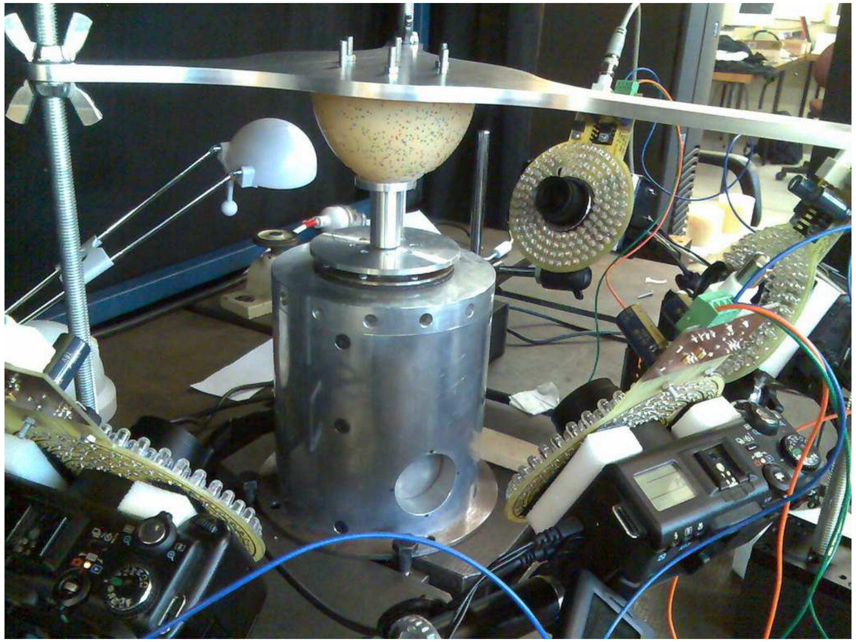
Example of points tracked



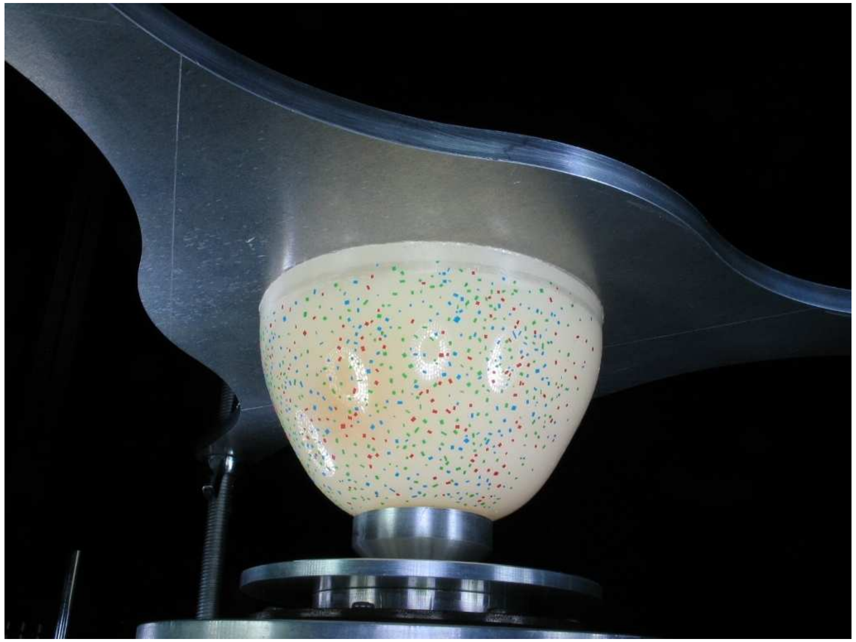
(a) whole set **(b) Subset (zoomed in)**

New results

Breast shaped phantom with "chest wall"

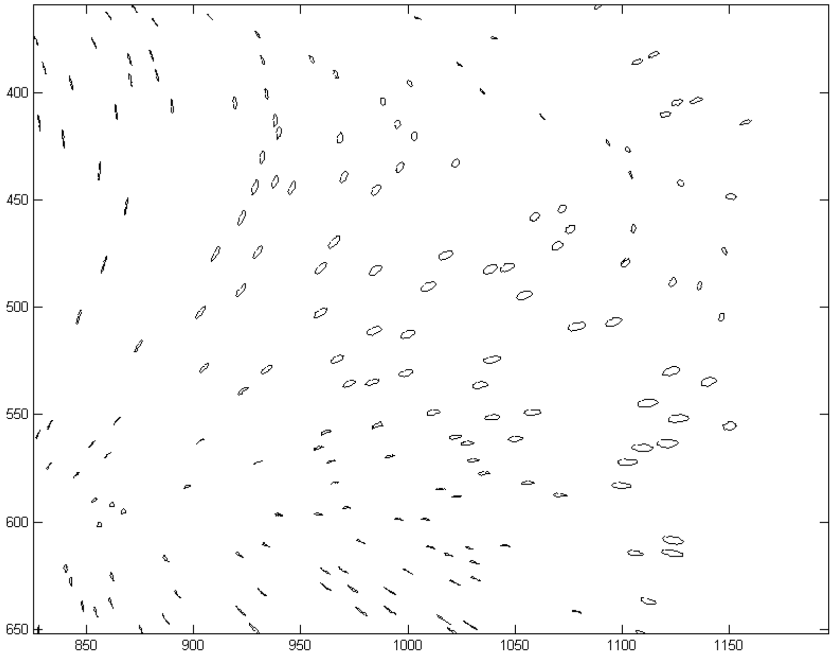


Experimental setup: Actuator, gel phantom, and four cameras fitted with LED ring flashes

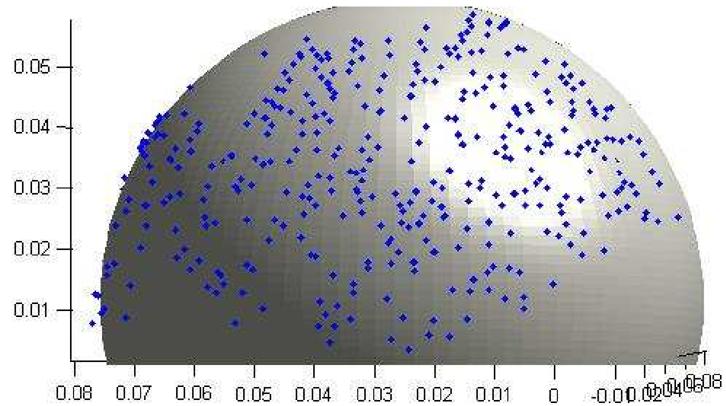


Silicon phantom under actuation with coloured dots applied

Tracking and reconstruction results



Close up of the tracked points from one camera

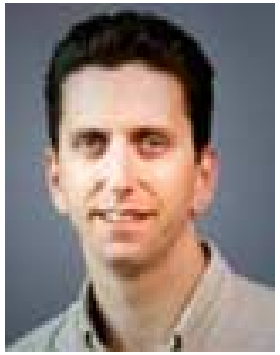


Reconstructed 3D surface points, with a least squares sphere in the background to give some 3D context

Conclusions

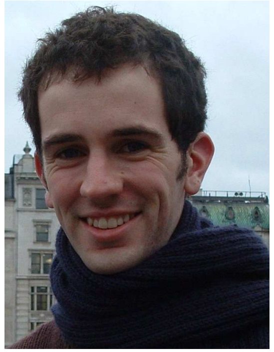
- **Accurate surface motion reconstruction for both cylindrical and realistically shaped breast phantom**
- **Image capture system successfully tested from 50-100 Hz**
- **All key issues of: Digital image acquisition; camera calibration; surface reconstruction and point tracking were addressed**
- **End result is highly accurate tissue surface motion tracking ➔ goes into a finite element based inverse problem that identifies tissue distribution of phantom**
- **In the case of a breast, regions of high stiffness would suggest a tumour**
- **Future Work:**
  - **Further realistic Breast phantom tests → Clinical trials**

Acknowledgements



Prof. Geoff Chase

Dr. Chris Hann



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And Larry Ray
from Care Stream
Health

Questions ???