



backend of the visualisation software, using parallel and grid-based supercomputing, such that visualisation can be achieved in an amount of time that is acceptable in the routine clinical setting.

### **3 Project over Duration of Funding**

#### **3.1 Were there significant changes to the Project or the objectives (yes/no)? If yes, give details.**

Yes. This was described in Progress Report 7. In summary:

The project proceeded as planned but it was decided not to colour code all of the original data, nor to have a radiologist evaluate the visualisation/tracing software using this data, because an opportunity arose to obtain 30 new data sets (with findings confirmed by histopathology) with higher spatial and temporal resolution. The new data provided an opportunity to “ground truth” the entire extent (in 3D) of suspicious lesions rather than just regions-of-interest within lesions.

#### **3.2 Did anything affect the satisfactory and timely progress or completion of the Project (yes/no)? If yes, please briefly describe what happened.**

Yes. This issue was described in Progress Report 4. In summary:

- Data normalisation proved to be more difficult than initially anticipated. This necessitated several changes/refinements to our normalisation methodology and concomitantly to the colour-coding and visualisation algorithms/software.

### **4 Project Outcomes and Impacts**

#### **4.1 Did the project meet its initial objectives or approved revised objectives (yes/no)?**

Yes

#### **4.2 Describe briefly the significance, results and outcomes of the project?**

Dynamic contrast-enhanced (DCE) magnetic resonance imaging (MRI) of the breast is becoming more widely used in the clinical setting as a supplemental imaging modality to conventional x-ray mammography. Current practice involves the manual review of the four-dimensional (4D) data acquired during an examination and of derived difference images. Not only is the data set high in dimensionality, it is large in size. This makes the task of review and interpretation by the radiologist both complex and difficult and the cost of missed diagnosis is high.

The parametric mapping and visualisation software developed for this project reduces the dimensionality of the task for the radiologist because it permits visualisation of the 4D data set as a single colour-coded volume. As outlined in Progress Report 5, we experimentally evaluated the software using 14 datasets from routine clinical practice. The experimental results show that using the visualisation/tracing tool a medically trained operator can achieve the same sensitivity for the detection of malignant lesions as a radiologist using conventional

manual interpretation, but with better specificity and without the need to review the entire 4D data.

As outlined in Progress Report 3, we investigated Star-P (Interactive Supercomputing Inc.) as a tool for parallelising the computationally-intensive model-fitting backend of our visualisation software. Conceptually Star-P permits existing MATLAB code, with appropriate restructuring and syntax changes, to perform parallel computation by transparently making use of multiple processors on a high performance computer (in our case a 20 processor SGI Altix 350). Unfortunately, after consulting with colleagues and QCIF staff, we were not able to find a suitable construct in MATLAB for vectorising our model-fitting code; i.e. we were not able to remove the “for” loops over all voxels. We instead ported our MATLAB model-fitting code to C. This permits model-fitting to a single 512×512 slice image in around 10 seconds on a 3 GHz Pentium 4 PC. Thus model-fitting of a whole volume is possible in around 5 minutes. Using QCIF’s SGI Altix 3700 Bx2 supercomputer with 64 processors it is possible to farm out single slice model-fits to individual processors and fit a whole volume in a matter of seconds.

In summary, the results and outcomes of this project are as follows:

### **1. Data acquisition and "ground truthing"**

75 low-resolution DCE-MRI data sets and 20 high-resolution data sets have been obtained and "ground truthed" by a radiologist and/or radiographer.

### **2. Algorithms/software**

- Software for interactive visualisation of colour-coded breast volumes, computed from 4D dynamic contrast-enhanced MRI data of the breast. The software runs on a standard desktop computer with a high-end graphics card; e.g. NVIDIA GeForce 6600.
- Software (C-code and UNIX shell scripts) to perform the computationally-intensive model-fitting (of our linear/slope model using segmented linear regression) to produce the colour-coded data for our visualisation software.
- A plug-in for ImageJ (National Institutes of Health, <http://rsb.info.nih.gov/ij/>) that can produce a colour-correct HSV maximum intensity projection (MIP) for rendering a 3D colour-coded breast volume.
- Two novel algorithms for correcting for patient movement in the 4D DCE-MRI data: one based on *iterated dynamic programming*, and the other based on control-point distortion and polynomial interpolation.
- UNIX shell scripts permitting model-fitting and motion correction for individual MRI slices to be trivially farmed out to the individual CPUs on a 20 CPU SGI Altix 350.
- Tracing/labelling software permitting a radiologist/radiographer to "ground truth" the raw 4D DCE-MRI data, and also to trace and label suspicious lesions in our 3D colour visualisations.

### **3. Experimental evaluation**

- The visualisation/tracing software above was experimentally evaluated using 14 DCE-MRI data sets from routine clinical practice. The results show that using the software a medically trained operator can achieve the same sensitivity for the detection of malignant lesions as a radiologist using conventional manual interpretation, but with better specificity and without the need to review the entire 4D data.

**4.3 Did the project lead to exciting new research directions, innovations and/or collaborations, and/or lay the foundations for new research and/or new partnerships? (yes/no)? If yes, please describe briefly how.**

Yes

- We established collaboration with the Centre for Image Analysis, Uppsala University, Sweden to develop the hardware-accelerated volume visualisation software. We intend to further this collaboration to develop software for interacting with the 3D colour-coded breast volumes using a haptic workstation.
- We are continuing our collaboration with Queensland X-Ray, Greenslopes Private Hospital. The nature of this collaboration includes the acquisition of additional data, "ground truthing", and evaluation of software/algorithms by clinical staff.
- The results of this project, in part, were used to support an ARC Discovery Project application for funding in 2008 (no. DP0879250). This application was successful and permits an investigation of machine vision algorithms for detecting/classifying suspicious breast lesions, and the possibility of fusing anatomical and diffusion-weighted MRI image data with the DCE-MRI data to improve the sensitivity and specificity of MRI for the detection of breast cancer.

**5 Research Collaboration**

**5.1 Collaborating Institutions**

<i>Name of institution/organisation</i>	<i>Type of Inst/Org</i>	<i>Country</i>
Queensland X-Ray, Greenslopes Private Hospital	A proprietary limited company providing diagnostic imaging services in Queensland.	Australia

**5.2 Summarise briefly the nature and extent of the collaborative arrangements.**

*Include comments on the extent of the involvement of the Collaborating/Partner Organisations and how beneficial the involvement was to the outcomes of the project.*

Queensland X-Ray provided the breast MRI data needed for this project. In addition it provided the consultancy time of a radiologist and radiographer necessary to "ground truth" this data and to evaluate the software developed. Without this collaboration the project would not have been possible.

**5.3 Provide details of any other collaborations or partnerships the research involved or led to. As appropriate, list the name, type of organisation and country of location.**

<i>Name of Inst/Org</i>	<i>Type of Inst/Org</i>	<i>Country (if not Australia)</i>
-------------------------	-------------------------	-----------------------------------

Centre for Image Analysis, Uppsala University	University Centre	Sweden
--	-------------------	--------

## 6 Project Outputs

### 6.1 Publications and other academic outputs

**(Enter the number of publications in each category. Where appropriate, enter full publication details; include 'published' and 'in press' publications, but exclude 'forthcoming' and 'submitted work'.)**

Item	Category	Number	Publication Details
E1	Conference—full written paper— refereed proceedings	2	<ol style="list-style-type: none"> <li>Erik Vidholm, Andrew Mehnert, Ewert Bengtsson, Michael Wildermoth, Kerry McMahon, Stephen Wilson, and Stuart Crozier: Hardware-accelerated volume visualisation of parametrically mapped dynamic breast MRI data, In <i>Proceedings of the Interaction in Medical Image Analysis and Visualization Workshop, 10th International Conference on Medical Image Computing and Computer Assisted Intervention (MICCAI 2007)</i>, Brisbane, Oct 29-Nov 2, 2007, p.33-40 (ISBN: 13: 978 0 643 09521 2).</li> <li>A. Hill, A. Mehnert, S. Crozier, C. Leung, S. Wilson, K. McMahon and D. Kennedy. Dynamic breast MRI: Image registration and its impact on enhancement curve estimation, In <i>Proceedings of the 28th IEEE EMBS Annual International Conference</i>, New York City, USA, Aug 30-Sept 3, pp. 3049-3052, 2006 (ISBN: 14244-0033-3).</li> </ol>

### 6.2 Publications and other academic outputs pending

Item	Category	Number	Publication Details
C1	Journal article—articles in scholarly refereed journal	1	<ol style="list-style-type: none"> <li>Andrew Hill, Andrew Mehnert, Stuart Crozier, and Kerry McMahon: Evaluating the Accuracy and Impact of Registration in Dynamic Contrast-Enhanced Breast MRI, submitted to <i>Medical Image Analysis</i>.</li> </ol>

## 7 Research Training, Careers And Employment

### 7.1 Postgraduate research training – Australian postgraduates supported by this project

Number of PhD students receiving stipends and project support	1
Number of research Masters students receiving stipends and project support	0
Number of PhD students receiving project support but not stipends	1

Number of Masters students receiving project support but not stipends	0
Number of Honours students receiving project support but not stipends	0

## **7.2 Postgraduate research training – Overseas postgraduates supported by this project**

Number of overseas PhD students involved in the project	1
Number of overseas research Masters students involved in the project	0
Number of overseas Honours students involved in the project	0

## **7.3 Early career researchers**

Early career researchers are researchers with up to 5 years postdoctoral experience

ECRs named in the application: Andrew Mehnert
---

## **7.4 Other employed personnel**

Number of research associates/assistants funded (full time)	0
Number of research associates/assistants funded (part time)	1
Number of professional and/or technical officers	0
Industry Partner employees (not PIs)	0
Other personnel involved (provide details below)	0

# **8 Certifications**

## **8.1 Certification by first-named investigator**

I certify that:

- This is an accurate Final Report; and
- All named investigators are in agreement that this report is an accurate representation of the current progress of the project.

1st-named Investigator signature \_\_\_\_\_

Date \_\_\_\_\_