An adaptive patient specific deformable registration for breast images of positron emission tomography and magnetic resonance imaging using finite element approach

Cheng XUE，Dr. Fuk-Hay Tang*

The Hong Kong Polytechnic University, Hong Kong SAR, CHINA

ABSTRACT

A patient specific registration model based on finite element method was investigated in this study. Image registration of Positron Emission Tomography (PET) and Magnetic Resonance imaging (MRI) has been studied a lot. Surface-based registration is extensively applied in medical imaging. We develop and evaluate a registration method combine surface-based registration with biomechanical modeling. .Four sample cases of patients with PET and MRI breast scans performed within 30 days were collected from hospital. K-means clustering algorithm was used to segment images into two parts, which is fat tissue and neoplasm [2]. Instead of placing extrinsic landmarks on patients' body which may be invasive, we proposed a new boundary condition to simulate breast deformation during two screening. Then a three dimensional model with meshes was built. Material properties were assigned to this model according to previous studies. The whole registration was based on a biomechanical finite element model, which could simulate deformation of breast under pressure.

Keywords: breast deformation, finite element analysis, explicit contact analysis, registration

1.INTRODUCTION

Breast cancer is the second leading cause of death in women (after lung cancer). Once women diagnosed with breast cancer, their quality of life will be severely influenced. The risk of developing breast cancer depends on many factors including age, personal or family history of breast cancer, parity, age at first birth and hormonal replacement. Since over 70% of breast cancer cases do not have any identifiable risk factors, the early diagnosis of it becomes utmost important.

According to cancer facts and figures published in 2013 in the United States [1], the most common type of cancer is prostate cancer, with more than 238,000 new cases expected. The next most common type of cancer is breast cancer, with more than 232,340 new cases. Approximately 10% of women are confronted with breast cancer in their lifetimes. In the US, about 1.4 million new cases were detected in 2008, but the incidence rates vary differently in different countries by more than 13-fold [2]. Breast cancer can be treated effectively when it was detected at the early stage, and the prognosis depends heavily on the tumour size [3]. When a suspicious lesion is detected, a biopsy is needed for the confirmation and staging of cancer [4].

Although breast biopsy is a highly specific and sensitive method for the diagnosis of breast cancer, it is invasive and will leave scar tissue that will confound future breast examinations. Moreover, biopsy has a relatively high false negative rate approach to 50%, probably due to the poor technique during biopsy [5]. Therefore, it is desirable to have other non-invasive imaging techniques (PET, CT, MRI and X-ray mammogram) to follow up an occult breast lesion.

Early detection of breast cancer has been proved to be significant by experts. Molecular imaging technology such as positron emission tomography (PET) can reflect in vivo molecular activities that can let early diagnosis of breast cancer come true. However, even though with high performance in reflection of functional information, PET is limited in demonstration of structure. Difficult exist in location of suspected region because of fuzzy structural information. Compared to PET, Magnetic Resonance Imaging (MRI) is good at showing soft tissue structure with lower signal in suspected cancer. Registration of PET and MRI can add the strength of both PET and MRI together to cover limitation. As breast deformation occurs in different body position, respiration, which is non-rigid and non-linear. This deformation is based on tissue organisation, temperature, body position. Registration only based on single image is not realistic to reflect accuracy anatomic information. Three dimensional registration can simulate breast's deformation based on actual pressure and gravity, deformation between slices is count in this process. Finite element model (FEM) has been used to simulation deformation of lung and liver during surgery. Here, we use FEM to simulation breast's deformation between scanning of two different image modalities, which is PET and MRI, so that these two images acquired at different time

Medical Imaging 2014: Image Processing, edited by Sebastien Ourselin,
Martin A. Styner, Proc. of SPIE Vol. 9034, 90343H · © 2014 SPIE
CCC code: 1605-7422/14/$18 · doi: 10.1117/12.2043252

and place can be registered in maximum level. Different breast imaging modalities bring complementary information that can help to make a diagnosis or assist the clinician for a therapeutic gesture. Researchers have been working on inter-modality breast image registration for a long time.

Image registration includes inter-modality registration and intra-modality registration. The modalities involved are X-ray mammography, MR mammography and ultrasound. X-ray mammogram registration is a 2-D/2-D registration problem, while the other two are 3-D/3-D registrations. Inter-modality breast image registration techniques include: X-ray mammography and MRI registration, MRI and ultrasonography registration, positron emission mammography (PEM), Positron emission tomography (PET) and CT registration, PET and MRI registration, and registration of X-ray mammography and ultrasonography [6]. In this section we will concentrate on inter-modality image registration. As a result, to enhance image quality of PET, we need to develop a registration process to fuse PET images with another imaging modality. Magnetic Resonance Imaging (MRI) is a kind of imaging technology that can reflect anatomy structure clearly Since patients may not get PET and MR scan at the same time, hence, registration of PET and MRI is still necessary.

PET is a kind of molecular imaging modality which can reflect the metabolic pathways and dynamic processes in vivo. Using of this technology can let the early detection of breast cancer come true, at the molecular level to achieve early diagnosis and treatment. However PET has its drawback of low resolution, the structure information in PET images is not clear enough for location of lesions in vivo. To enhance image quality of PET, we need registration process to fuse PET images with another imaging modality. Different from previous study, we use both eastern female and western female breasts in our project to evaluate our model. The existing registration method is very time-consuming which would affect early diagnosis of breast cancer. Too many process of images lost specific clinical features, this will lead to inaccuracy of registration and later diagnose and treatment. In this project, we are going to establish a registration method for PET and MRI, which can reflect patient specific features, shorten the computation time and increase accuracy in the mean time. The modelling part is finished with a set of commercial software, then the whole process is more convenient and more adapt to clinical diagnosis. Image registration is a process that fuse two images together according to correspondence features from different images in one image, or a temporal sequence of images, so that treatment effect can be evaluated. In clinical, image of patient may took from different image modalities or at different time. Location of image features which are important for diagnosis is necessary, but because of the fact that this image may took under different body position. For instance, when patient accept a MR scan, their position should be prone position. While, for mammogram, breast was pressed by two parallel plate. Also, for PET scan, the common position is opposite with MRI. In case of the fact that breast consist of soft tissue, the deformation caused by body movement and gravity is non-rigid deformation, it may includes not only rotation and shift, but also movement between slice. Registration based on two dimensional image can not reflect real movement of breast. In this paper, we establish a three dimensional registration model based on contact element analysis.

FEM has been used in engineer area for a long time, it has strong calculation power that can simulate large deformation. Now days, this method has attracted bio-medical engineers' attention to simulating organ deformation during surgery or predict deformation after cosmetic surgery such as orthodontics and breast shaping surgery. Biomechanical models can help clinician to make diagnosis plan and predict surgery result just by computer, also are able to reduce risk of failure. Breast deformation can be considered as a quasi-static problem and both dynamic model and implicit model has been established to finish simulation using finite element analysis strategy.

Material property has been proven to be the most important impact factor that influence soft tissue deformation state. Many researchers had conducted studies to measure the elasticity parameters of soft tissues [7, 8]. According to these studies the average Young' modulus value for fatty tissue is 1KPa, for skin is 88KPa, for glandular tissue is 10KPa. The overall Young's modulus is considered to lie in the range 5KPa-15KPa for the entire breast modelled as a linear, continuous, incompressible, isotropic and homogenous tissue.

The modelling of biomechanical tissue has gained considerable interest in a range of clinical and research applications. According to literature, in the domain the breast is considered to be made of biological soft tissues, which are known to be incompressible. The female breast is originally composed of four structures: lobules or glands, milk ducts, fat and connective tissue. The breast tissues are connected with overlying skin by Cooper's ligaments, which are kinds of fibrous strandsv[9]. Most biologic tissues have both a viscous and an elastic response to external deformations. As we are interested only in slow deformations, the response of the tissue can be considered entirely due to elastic forces [7]. All tissues in the breast can be considered anisotropic, incompressible and inhomogeneous with nonlinear elastic properties for large deformations. The Young modulus represents how much a material will deform when a load is applied, and

Poisson ratio express how much a material will shrink in one direction when it is stretched in a perpendicular direction, an incompressible material will conserve the volume so same volume stretched must be shrunk. Since breast tissues exhibit a nonlinear behaviour for large deformations the Young's modulus can be considered as a function of strain for each tissue:

2. METHODOLOGY

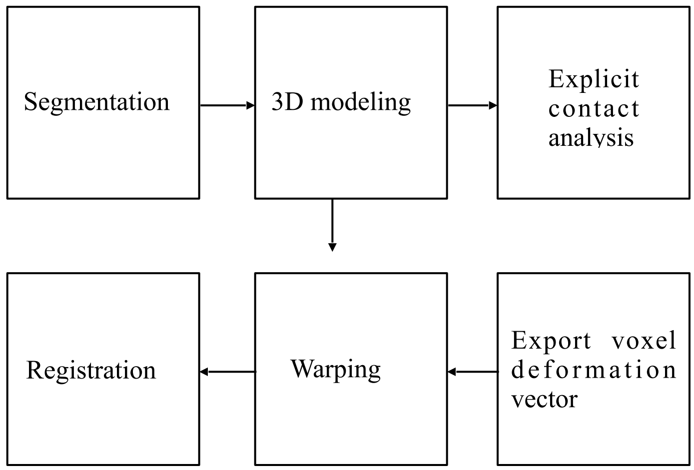

Figure 1. Framework of modelling process

Three dimensional model will be built based on segmented images. As shown in Figure 1, after contact analysis, voxel deformation vector can be obtained to generate deformed image. As the shape of the breast looks like a half ball, in our pilot study a half ball model was built in TET network, which means tetrahedron. For TET mesh, a force equal to 10KN and gravity was added to the surface, we prepare the surface as zero displacements. The time cost for analysis in element size was calculated to ascertain a suitable element size. We can see from Figure 2 that computation that will incredibly increase when it is smaller than 2. According to the number of nodes and computer time, an element size of 2 was chosen.

Table 1. Number of nodes and elements

Element Size	Number of nodes	Number of elements	Time (s)
10	214	86	11
8	180	86	11
4	1413	291	13.4
2	4042	2212	15.3
1	24241	14415	23.5

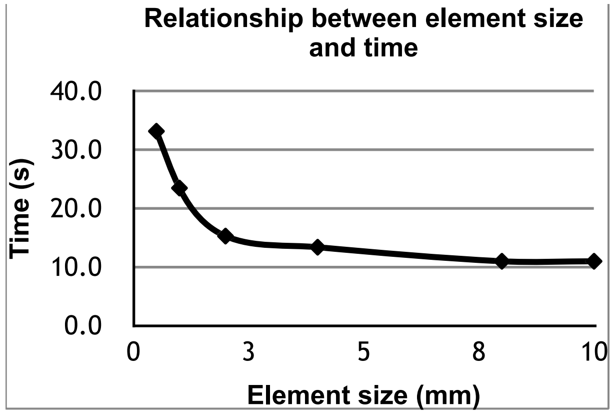

Figure 2. Relationship between element size and time

In this part, process of generating a patient specific breast model will be described. Four sets of MR and PET images come from the same patient between one month were collected from hospital, all the information has been anonymised.

2.1. surface modelling

Mimics calculate surface 3D models from stacked image data, such as Computed Tomography , Micro CT, Magnetic Resonance Imaging , Microscopy and Ultrasound, through image segmentation. The ROI, selected in the segmentation process is converted to a 3D surface model using an adapted marching cubes algorithm that takes the partial volume effect into account, leading to very accurate 3D models. Mimics (Materialise NV, Belgium) is a software specially developed by Materialise for medical image processing. Use Mimics for the segmentation of 3D medical image and the result will be extremely accurate 3D models of patient's anatomy. 96 slices MR images were stacked to construct the volume in Mimics to finish modeling of breasts. During this process we defined different masks based on the image intensity difference of each tissue. The export models were highly patient specific. In this step fat and cancer was labeled as two parts for future analysis. After segmentation, we generate a point based model in *.stl form without noise. Then this *. stl file was imported into Rapid form to transform point based models into a solid model, to refine the surface and smooth sharp edge which will cause aborts in FEA. An Initial Graphics Exchange Specification (IGES) file was generated after this step, this file defines a vendor neutral data format that allows the digital exchange of information among Computer-aided design (CAD) systems.

Table 2. Model type of Finite Element Analysis

Model type	AIN	HL	GHL
Young's modulus	Previously defined equations for Young's modulus	Fat: 1 KPa Carcinoma : 16.5 KPa	10KPa
Poisson's ratio	N/A	0.490	0.490

The IGES file produced in the modeling part was imported to ABAQUS as a part. Following material properties were assigned. Section area was defined as solid, homogeneous and assigned to part as mentioned before .In the mesh step, we choose C3D10M as element shape with ten nodes, element size equal to 2 which was gotten form pilot study. Because of the complex geometry of the breast solid model and the size of the element resulted in a small percentage of bad shaped elements. This could be alleviated by further reducing the element size but this would lead to a large number of elements and nodes and a long computational time. Eventually, we decide a 1.5 element size, this value for element size is acceptable regarding computational time, the percentage of bad shaped elements and final result error. Further reduction of the element size would have no effect on the outcome.

2.2. Explicit solver

Explicit solver is a kind of dynamic solver, it is developed to simulate high speed impact problem at first. The rationale of explicit analysis is that for any point on slave surface may contact with more than one point on master surface, explicit analysis can track surface movement with mature search algorithm. We can identify that Explicit solver is appropriate for simulation of soft tissue. So in this study, we choose Explicit as our solver.

3. RESULTS

We have used Explicit contact analysis to generate surface deformation of the half ball model (Figure 4, Figure 5). High accuracy three dimensional breast model has been built (Figure 3).

Figure 3. meshed model of PET and MRI (a) PET (b) MRI

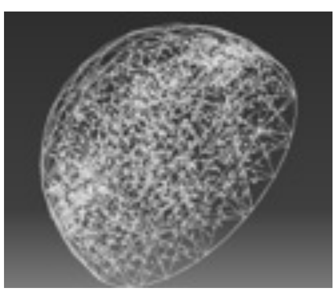

Figure 4. Symbols plots

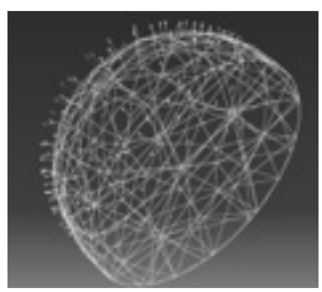

Figure 5. Displacement plots

4. CONCLUSION AND DISCUSSION

In this study, a patient specific breast deformation simulation model has been partially established. This method is very convenient and easy to use. However, the model that will access contact analysis can not have intersection surface, this is not reliable for all the model in clinical. Also the material property of this method is assigned based on previous studies, while, this value is dependent on temperature age and position, constitutive model of a hyperelastic material is defined by a total stress versus total strain relationship derived from a strain energy function, which is more accurate when it comes to simulation of breast deformation. In the following study, we may consider assign a hyperelastic material parameters to our model.

5. REFERENCE

[1] *Cancer Facts & Figures 2013*.

[2] *American Cancer Society: Cancer Facts and Figures 2013.* .

[3] D. Brinkley and J. Haybittle. The curability of breast cancer. *The Lancet 306(7925),* pp. 95-97. 1975.

[4] A. Mendez, F. Cabanillas, M. Echenique, K. Malekshamran, I. Perez and E. Ramos. Evaluation of breast imaging reporting and data system category 3 mammograms and the use of stereotactic vacuum−assisted breast biopsy in a nonacademic community practice. *Cancer 100(4),* pp. 710-714. 2004.

[5] L. Delle Chiaie and R. Terinde. Three−dimensional ultrasound−validated large−core needle biopsy: Is it a reliable method for the histological assessment of breast lesions? *Ultrasound in Obstetrics & Gynecology 23(4),* pp. 393-397. 2004.

[6] Y. Guo, R. Sivaramakrishna, C. Lu, J. S. Suri and S. Laxminarayan. Breast image registration techniques: A survey. *Medical and Biological Engineering and Computing 44(1-2),* pp. 15-26. 2006.

[7] F. S. Azar, D. N. Metaxas and M. D. Schnall. A deformable finite element model of the breast for predicting mechanical deformations under external perturbations. *Acad. Radiol. 8(10),* pp. 965-975. 2001.

[8] J. A. Schnabel, C. Tanner, A. D. C. Smith, D. L. Hill, D. J. Hawkes, M. O. Leach, C. Hayes, A. Degenhard and R. Hose. Validation of non-rigid registration using finite element methods. Presented at Information Processing in Medical Imaging. 2001, .

[9] C. Tanner, A. Degenhard, J. A. Schnabel, A. D. Castellano-Smith, C. Hayes, L. I. Sonoda, M. O. Leach, D. Hose, D. L. Hill and D. J. Hawkes. Comparison of biomechanical breast models: A case study. Presented at Medical Imaging 2002. 2002, .