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ADAPTIVE KERNEL INTERPOLATION ON 3D IMAGE RECONSTRUCTION OF BREAST ULTRASOUND IMAGES

NG PAUL YONG

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By

NG PAUL YONG

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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January 2018

Chairman : Prof. M. Iqbal Bin Saripan, PhD
Faculty : Engineering

Three-dimensional ultrasound imaging is getting popular due to the ability to visualize volumetric representation of tissues and organs while having non-ionizing radiation properties. This project aims to reconstruct a 3D ultrasound image from series of B-Scan images. 3D ultrasound image allows better overview of whole organ. Holes will appear during the reconstruction process due to the reason that pixels will always be small when comparing to real world spatial measurement. The process of finding potential holes pixel by pixel takes huge computation cost. Besides, conventional interpolation technique uses fixed kernel size which does not tackle holes of different size. There will be some holes that are too far for the kernel to reach out and there will be holes that are just one pixel away from filled pixel. Thus, using a fixed sized kernel waste computation resources. A technique of reconstructing the image volume is introduced. Ultrasound probe will be rotated 360° around the breast to capture each image individually. Fan-like 3D image is formed with this technique of image acquisition. A new technique is introduced to find interested holes in a faster approach by convoluting the image with a smaller size kernel. This technique tackles the problem of finding holes pixel by pixel. This approach will reveal interested holes by tagging each holes with value to represent how far away the filled pixels are. Nonetheless, the existing technique that deals with hole-filling uses nearest neighbour interpolation with fixed kernel is slow and inefficient. The goal is to develop a hole-filling technique that uses variable sized kernel on nearest neighbour and Gaussian interpolations. The improvement of the Gaussian interpolation technique is done with an addition of sigma filter. Gaussian interpolation uses values from nearest neighbour as local mean and computes the local variance accordingly. Sigma filter helps remove noise by eliminating values that difference the mean by more than two sigma. Results of proposed technique are interpreted quantitatively. Homogenous and non-homogenous region are extracted and compared. Gaussian interpolation with sigma filter gives the best result in both homogenous and non-homogenous area. The quantitative study of each technique are compared in terms of standard deviation,

average absolute difference, iteration, time, kernel distribution. The proposed methods produced 80% of the kernel that distributed in the kernel size of 1 and 2 in nearest neighbour interpolation. As for Gaussian interpolation, 50% of the kernels used are kernels of size 2 and 3, and 30% left in kernel size of 1 and 4. The iteration and time required for the proposed holes-finding and holes-filling technique has improved up to 4 times faster compared to conventional methods. The addition of sigma filter manages to suppress noise while keeping edge details. To conclude, a more efficient system is shown to reconstruct raw B-Scan image into 3D image that could be visualized using 3D visualization tools easily while improving the conventional way to interpolate the holes.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan Ijazah Master Sains

PEMBINAAN SEMULA IMEJ 3D UNTUK IMEJ ULTRABUNYI PAYU DARA MENGGUNAKAN INTERPOLASI PEMBOLEHSUAIAN KERNEL

By

NG PAUL YONG

Januari 2018

Pengerusi: Prof. M. Iqbal Bin Saripan, PhD
Fakulti: Kejuruteraan

Pengimejan ultrabunyi tiga dimensi semakin popular kerana kemampuan untuk memvisualisasikan volumetrik tisu dan organ di samping mempunyai sifat radiasi yang bukan ionisasi. Projek ini bertujuan untuk membina semula imej ultrabunyi 3D dari siri imej B-Scan. Imej ultrasound 3D membolehkan gambaran keseluruhan organ yang sempurna. Lubang-lubang akan muncul semasa proses pembinaan semula atas alasan piksel akan sentiasa lebih kecil apabila dibandingkan dengan ukuran ruang dunia sebenar. Proses mencari lubang yang berpotensi satu piksel demi satu piksel memerlukan kos pengiraan yang besar. Selain itu, teknik interpolasi konvensional menggunakan kernel yang bersaiz tetap dan tidak menangani lubang yang berbeza saiz. Seperti yang diketahui, mungkin terdapat beberapa lubang yang terlalu jauh yang boleh dijangkau oleh kernel dan akan ada lubang yang jaraknya hanya satu piksel jauh dari piksel yang bernilai. Oleh itu, penggunaan kernel bersaiz tetap membazir kos pengiraan. Projek ini memperkenalkan teknik membina semula 3D imej. Prob ultrabunyi akan diputar 360° di sekitar payudara untuk menangkap setiap imej secara individu. Imej 3D seperti kipas dibentuk atas teknik pengambilan imej ini. Projek ini memperkenalkan teknik baru untuk mencari lubang-lubang yang berpotensi dengan lebih pantas dengan mekonvolusikan imej dengan kernel yang lebih kecil. Teknik ini boleh menangani masalah untuk mencari lubang piksel demi piksel. Cara ini akan mendedahkan lubang yang berpotensi dengan menandakan setiap lubang dengan nilai yang mewakili jarak dengan piksel yang berisi. Walau bagaimanapun, teknik sedia ada yang menggunakan interpolasi jiran terdekat untuk mengisi lubang dengan menggunakan kernel yang berssaiz tetap adalah lambat dan tidak efisien. Matlamat projek ini adalah untuk mencari teknik pengisian lubang yang menggunakan kernel saiz yang berubahsuai dalam interpolasi jiran terdekat dan interpolasi Gaussian. Penambahbaikan teknik interpolasi Gaussian boleh dilakukan dengan penambahan penapis sigma. Interpolasi Gaussian menggunakan nilai dari interpolasi jiran terdekat sebagai purata tempatan untuk mengira varians tempatan. Penapis Sigma membantu menghilangkan hingar dengan menghilangkan nilai-nilai yang berbeza daripada

purata melebih dua sigma. Keputusan teknik ini ditafsirkan secara kuantitatif. Kawasan homogen dan tidak homogen diekstrak dan dibandingkan. Interpolasi Gaussian dengan penapis sigma memberikan keputusan yang terbaik dalam kawasan homogen dan bukan homogen. Kajian kuantitatif bagi setiap teknik dibandingkan dari segi sisihan piawai, purata perbezaan mutlak, lelaran, masa, dan pengagihan kernel. Kaedah ini menghasilkan 80% kernel yang diagihkan ke saiz kernel 1 dan 2 dalam interpolasi jiran terdekat. Bagi interpolasi Gaussian, 50% daripada kernel yang digunakan adalah kernel bersaiz 2 dan 3, dan 30% lagi dalam saiz kernel bersaiz 1 dan 4. Iterasi dan masa yang diperlukan untuk teknik mencari lubang dan mengisi lubang telah meningkat sehingga 4 kali lebih pantas berbanding dengan kaedah konvensional. Penambahan penapis sigma dapat mengurangkan hingar dan mengekalkan pinggir imej. Kesimpulannya, projek ini menyediakan sistem yang lebih efisien untuk membina semula imej B-Scan kepada imej 3D yang dapat divisualisasikan dengan menggunakan alat visualisasi 3D dengan mudah sambil menambah baik cara konvensional untuk menginterpolasi lubang.

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M. Iqbal Bin Saripan, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Rozi Binti Mahmud, MD
Professor
Faculty of Medicine and Health Science
Universiti Putra Malaysia
(Member)

Syamsiah Binti Mashohor, PhD.
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Name of Chairman of Supervisory Committee: Prof. M. Iqbal Bin Saripan

Signature: ______________________________
Name of Member of Supervisory Committee: Prof. Dr. Rozi Binti Mahmud

Signature ______________________________
Name of Member of Supervisory Committee: Dr. Syamsiah Binti Mashohor

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
DOF	Degree of Freedom
DW	Distance Weighted
ECG	Electrocardiographic
FASC	Full Angle Spatial Compounding
FBP	Filtered Back Projection
FMM	Fast Marching method
NN	Nearest Neighbour
PCA	Principal Component Analysis
PVA	Polyvinyl Alcohol
ROI	Region of Interest
SAD	Sum of Absolute Difference
SDW	Square Distance Weighted
SURE	Sub-volume-based algorithm for elastic Ultrasound Registration
US	Ultrasound
VTK	Visualization Toolkit
RBF	Radial Basis Function

CHAPTER 1

INTRODUCTION

1.1 Background

Breast cancer is considered as the most common type of cancer in women group. Mammogram is used to image breast anatomy thus help detecting cancer in early stage. However, due to the invasive nature of X-ray, long exposure of X-ray radiation during mammogram might bring side effects. Besides, it is known that mammogram procedures are not comfortable as it is rather painful [1]. MRI however is a good imaging modality for breast, but the machine is rather expensive [2, 3].

Consequently, ultrasound (US) examination is sometimes a better option [4–6]. Ultrasound imaging modalities in the context of breast cancer diagnosis is limited by the physical principles of imaging modality. Ultrasound B-Scan image are prone to speckle noise. De-noising algorithm is needed to suppress the noise.

Outcome of B-Scan image is highly depending on the angle of the probe being held. Non-experienced operator may face trouble in finding abnormal cell. Even for experienced operator, they might miss out some spot during the scanning procedures. Ultrasound imaging is an acoustic imaging modality, the properties of sound wave create shadowing effect when a high attenuation cells blocked the wave [7]. This may lead to misdiagnoses. The limitation of 2D ultrasound can be overcome with 3D ultrasound imaging.

Generally, 3D US consist of three stages: scanning, reconstruction, and visualization [8]. Scanning process was done using 2D linear US probe. This process could be done using either free hand or mechanical hand. Positional sensor shall be added into the system to provide a precise determination of probe's location and orientation [9, 10]. Reconstruction process however will be dealing with bin-filling and hole-filling. Bin-filling is a procedure required to tackle cases where multiple US image overlaps due to the scanning pattern [11, 12]. Averaging the overlap parts is an example of bin-filling. Holes will be created during the scanning process. The higher the resolution of your 3D image, the bigger the hole will be. Even if the spatial gap between sequential scans is the same, there will be more empty pixels due to higher resolution. Hole-filling process makes use of image interpolation technique to fill up holes [13]. Lastly, there are a lot of library and software packages that can be used to visualize 3D US image. It could even be done in real time if the image resolution is small and the 3D reconstruction is fast enough.

1.2 Motivation for 3D ultrasound

2D ultrasound is widely used in diagnosing cancer. However, 2D ultrasound lacks spatial information. In 2D images, there is no way to identify the volume of cyst found. Besides, doctor needs to visualize the mental picture of 3D anatomy while doing the scanning process. It is impossible for complex 3D anatomy even for experienced specialists.

The introduction of 3D ultrasound could potentially solve the problem. There are several benefits of 3D ultrasound compare to 2D ultrasound. This includes the ability to visualize 3D image in a visualization system and be viewed in different plane such as sagittal, coronal and transverse plane together. The ability to slice each plane allows the doctor to look through the slices like a typical CT scan [14, 15]. The 3D image could be zooms and rotates accordingly by the doctors when interested spot was found. Moreover, due to the ability to save the 3D image as a whole, doctors can keep track of patient records and compare each diagnosis efficiently. The documentation of the examination for future reference is also possible. Moreover, this documentation could be useful in remote diagnosis.

3D ultrasound machine aims to be operator independent. The reconstructed image will cover all the area and angle hence it will not vary between operator when comparing to 2D ultrasound diagnosis. This may improve standardisation [16].

It is also possible for 3D ultrasound to reduce artefacts found in B-Scan image such as shadowing due to high attenuation by capture and compound images from two opposite side. It is known that ultrasound images are full of speckle noise, and 3D reconstruction of US image could potentially supress the speckle [17]. Averaging of compound image will reduce the noise while retaining the details if the position and orientation of each slice is known.

1.3 Problem Statement

2D B-Scan ultrasound image lacks volumetric information. Doctors need to imagine the structure of breast themselves. Besides, in 2D US, the volume and shape of cysts could not be identified. In 2D US, B-Scan US image can only be viewed perpendicular to skin, while in 3D US, the image in different plane or even at different angle can be viewed. For example, the image in the plane parallel to skin could not be done in 2D US. 3D US introduce more flexibility in viewing plane and angle.

Scanning techniques produces alternate view on how the final image looks. Serial scanning either in vertical or horizontal plane are commonly used in automated breast volume scanner [18, 19]. However serial scanning does not perform as well in some condition. When the imaging of ductal system is done through serial scanning, the distribution of ductal system is not well oriented [20, 21] similar to Figure 2.1. Both vertical and horizontal scanning produces sonogram will look very different from the previous scan. This is due to the reason that the scan cut across the ductal structure at different viewing angle. Besides, extra scan is needed to examine the tail of Spence [22]. The focal area of ductal ectasia could not be detected properly. Besides, lesions may falsely appear spheroid or ellipsoidal if the lesion is viewed in single plane. In serial scanning, there is no sense of location or a reference point; hence it is heavily relying on position sensor. Unlike radial scan that include nipple in each scan could provide good identification on its location [23]. That is why radial scanning was introduced for the study of dilated ducts.

Secondly, it takes huge computation time and cost looking for fillable holes pixel by pixel. Unlike zooming of images where holes location is fixed, in the reconstruction of 3D US image, holes are missing information and will be introduced in arbitrary location depending on probe's movement. Estimation of values to replace the holes is required so that the image can be viewed as a whole. Hence, to fill up the holes, surfing pixel by pixel looking for potential hole is slow. Besides, in the reconstruction progress, not all holes will be able to fill up. This is because the kernel of interpolation technique might not be large enough to reach a filled pixel. The wish is to eliminate those unfillable pixels.

Lastly, conventional interpolation technique uses fixed sized kernel throughout the whole image. As what was explained above, the holes location and size are arbitrary. Some holes are bigger and further away from filled pixel and some are just a pixel besides filled pixel. Hence it is not a logical approach to deal with all the holes using the same kernel size.

1.4 Aim and Objectives

The aim of this project is to reconstruct 2D breast US B-Scan image into 3D image by scanning the breast in a rotational fashion with known spatial information using interpolation technique to fill up the holes between images.

The objectives of this project are described as below:

a) To map 2D B-Scan images into 3D volumetric coordinate.
b) To develop an algorithm that locates and fills the fillable hole in a faster fashion.
c) To evaluate the performance of interpolation that makes use of adaptive size kernel in terms of average absolute difference, computation time and iteration.

1.5 Scope and Limitation

This study focus on reconstruction of 3D image using multiple slices of ultrasound images captured from different breast's location. Only one type of scanning technique will be used throughout the experiment which is rotation of probe around the breast.

Serial scan type is not considered. Unlike serial scan where gap between slices are measured in distance, in this technique of scanning, the slices differ from previous slice in angular gap. Hence, the holes finding and filling technique may not work as well in serial scan. Equally spaced data from serial scan may not be suitable to use the proposed holes finding technique as it only makes the work complex while having the same result. The proposed technique specialized in characterizing the hole based on its distance from filled hole without having to go through all the pixels one after another. As for holes filling / interpolation technique, only nearest neighbour and Gaussian interpolation are being investigated as this is the most common and easiest to implements techniques.

This project was done without positional sensor. Each image was taken manually on pre-marked location on the phantom. The location and orientation of probe will not be precise. The spatial information from positional sensor can be easily added and thus will be discussed in methodology. The orientation of probe was assumed to face the centre of phantom on each scan. The precise orientation is unknown due to absence of positional sensor. Besides, the probe is oriented to be perpendicular to the phantom base while touching the ground to limit the degree on freedom on probe's orientation. The pitch and roll has to be kept constant while recording the yaw rotation manually. Moreover, the movement of probe is also limited. The movement of probe in vertical axis is not accounted by limiting the probe to always touch the ground. The pressure applied on the phantom is arbitrary and hence the compression rate could not be identified in all the slices. Hence, the assumption is that the same compression rate of $13mm$ is used throughout the slices. Compression rate was calculated based on the difference in cyst location of B-scan and phantom specification sheet.

Only one phantom was used throughout the whole study which is Kyoto Kagaku's Ultrasound-guided breast biopsy transparent phantom with diameter of $136m$, height of $70mm$ and weighted $700g$. The targets are $6mm$ and $8mm$ in diameter. There is also a small deviation between the measured and on paper value as water based phantom may shrink over time.

The ultrasound machine used in this work is Mindray M7 pair with linear array ultrasound transducer from MindRay codename 7L4S having frequency at $5/7.5/10\ MHz$. $5MHz$ is the default frequency. The default output image from Mindray M7 is in jpeg format.

1.6 Contribution

a) A method that reconstruct 3D image from 2D B-Scan US image in rotational fashion is introduced.
b) A novel technique that identifies the location of fillable holes by convoluting the image with the proposed kernel is introduced.
c) Adaptive sized kernel interpolation technique based on the location of holes is used.

d) Sigma filter is added as part of interpolation technique for better noise rejection.

1.7 Thesis Organization

Chapter 1 describe the introduction of the project. It describes the background, problem statement, aim, objectives, and contribution of this project.

Chapter 2 contains literature review regarding this project. It describes the reconstruction of 3D US image from image acquisition technique, 3D image formation and visualization and also interpolation technique used to fill up holes.

Chapter 3 contains methodology proposed in this project. The creation of volume grid is discussed, pixel transformation from 2D plane to 3D plane, hole-finding technique and also hole-filling technique.

Chapter 4 contains results and discussion of the obtained results from the experiments. Image created after pixel transformation and image after different interpolation technique was shown. The performance of proposed hole-finding and filling technique and the conventional technique are compared quantitatively.

Chapter 5 concludes what this project had achieved and some suggestion of future work.

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