KIDNEY ABNORMALITY DETECTION AND CLASSIFICATION USING ULTRASOUND VECTOR GRAPHIC IMAGE ANALYSIS

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Dedicated to

Mak (Fatimah binti Haron) & **Where** (Wan Mahmud bin Wan Idris),

Beloved siblings, relatives, and friends

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ABSTRACT

Ultrasound imaging has been widely used in kidney diagnosis, especially to estimate kidney size, shape and position, and to provide information about kidney function, and to help in diagnosis of structural abnormalities like cysts, stone, and infection. However, the use of ultrasound in kidney diagnosis is operator dependent where the images may be interpreted differently depending on operators' skills and experiences, variations in human perceptions of the images, and differences in features used in diagnosis. Current kidney diagnosis may be improved by implementing automated techniques and computer aided diagnosis systems, but have not been widely explored. Therefore, this study proposed a vector graphic image formation method which enables the ultrasound images to be manipulated for various applications including region of interest (ROI) generation, cysts detection and segmentation and abnormality classification. Automatic kidney ROI generation algorithm able to achieve 89.6% true ROI when tested with 125 kidney images. Besides that, the vector graphic formation helps in detection and segmentation of cysts automatically with high accuracy (true positive area ratio = 0.9584, similarity index = 0.9439, Hausdorff distance = 11.4018) and less execution time (11.4 seconds). Performance evaluation to 50 single cyst images, and 25 multiple cysts images gave accuracy of 92%, and 86.89% respectively. This vector graphic formation also helps in extracting better features that successfully classify kidney ultrasound images into three different groups namely normal, infectious and cystic with testing and validation accuracy of 93.33% and 91.67% respectively ($p<0.05$). Overall, this study has shown promising results and implementation of these proposed algorithms into current kidney diagnosis technique may help in improving current diagnosis accuracy while reducing human intervention and operator dependency.

ABSTRAK

Pengimejan ultrabunyi telahpun digunakan secara meluas dalam diagnosis ginjal, terutamanya untuk menganggar saiz, bentuk dan kedudukan ginjal, mendapatkan maklumat tentang fungsi ginjal dan membantu mengesan struktur abnormal seperti *cysts*, batu karang dan jangkitan. Namun begitu, penggunaan ultrabunyi dalam diagnosis ginjal sangat bergantung kepada pengendali mesin, dimana imej ginjal akan ditafsirkan secara berlainan bergantung kepada kebolehan dan pengalaman pengendali, kepelbagaian dalam persepsi individu terhadap imej tersebut, dan perbezaan ciri yang digunakan untuk diagnosis. Diagnosis ginjal ini boleh diperbaiki dengan menggunakan teknik automatik dan sistem pengesanan berkomputer. Walau bagaimanapun, teknik ini masih belum dikaji dengan meluas. Justeru, kajian ini mencadangkan kaedah pembentukan imej grafik vektor (*vector graphic image formation*), yang membolehkan imej ultrabunyi dimanipulasikan untuk pelbagai kegunaan termasuk penjanaan rantau berkepentingan (ROI), pengesanan *cysts* dan pengelasan penyakit. Pengujian algoritma ROI secara automatik ke atas 125 imej ginjal menunjukkan ianya mampu mencapai 89.6% ketepatan ROI sebenar. Selain itu, pembentukan imej grafik vektor membantu mengesan dan mengasing *cysts* dengan ketepatan yang tinggi (nisbah kawasan positif = 0.9584, indeks kesamaan = 0.9439, jarak Hausdorff = 11.4018) dan masa yang singkat (11.4 saat). Penilaian prestasi terhadap 50 imej *cyst* tunggal dan 25 imej pelbagai *cysts* memberi ketepatan sebanyak 92% dan 86.89% setiap satunya. Pembentukan imej grafik vektor juga membantu mengekstrak ciri yang lebih baik dan berjaya mengelaskan imej ultrabunyi kepada tiga kumpulan, iaitu normal, jangkitan dan *cystic* dengan ketepatan pengujian dan penentusahihan (*validation*) sebanyak 93.33% dan 91.67% setiap satunya ($p<0.05$). Secara keseluruhan, kajian ini telah menunjukkan keputusan yang baik, dan pelaksanaan algoritma ini dalam diagnosis ginjal dapat memperbaiki ketepatan pengesanan sedia ada, selain mengurangkan campur tangan manusia dan kebergantungan terhadap pengendali.

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LIST OF ABBREVIATIONS

3D	-	Three dimensional
AC	-	Active contour
ADPKD	-	Autosomal dominant polycystic kidney disease
AI	-	Adobe Illustrator
ANN	-	Artificial neural network
ARPKD	-	Autosomal recessive polycystic kidney disease
BI	-	Bacterial Infection
BUN	-	Blood urea nitrogen
CAD	-	Computer aided diagnosis
CBIR	-	Content-based image retrieval
CC	-	Cortical cyst
CD	-	Cystic disease
CKD	-	Chronic kidney disease
CT	-	Computed tomography
DICOM	-	Digital imaging and communication in medicine
ESRD	-	End stage renal disease
FBME	-	Faculty of Biosciences and Medical Engineering
FN	-	False negative
FP	-	False Positive
GFR	-	Glomerular filtration rate
GLCM	-	Gray level co-occurrence matrix
GUI	-	Graphical user interface
HD	-	Hausdorff distance
IVP	-	Intravenous pyelogram
MDRD	-	Modification of diet in renal disease
MLP	-	Multilayer perception

MRD	-	Medical renal disease
MRI	-	Magnetic resonance imaging
MRF	-	Markov random field
MSE	-	Mean squared error
NR	-	Normal
PCA	-	Principal component analysis
PDF	-	Portable document format
PSNR	-	Peak signal to noise ratio
RGB	-	RGB image
RI	-	Resistive index
ROC	-	Receiver operating characteristic
ROI	-	Region of interest
RRT	-	Renal replacement therapy
SI	-	Similarity index
SPL	-	Spatial pulse length
SVG	-	Support vector graphics
SVM	-	Support vector machine
TP	-	True positive
US	-	Ultrasound
VBA	-	Visual basic for application
VUR	-	Vesicoulateral reflux
WV	-	Weight vector

LIST OF SYMBOLS

A	-	Area
A_m	-	Pixel set of manual outline
A_a	-	Pixel set of automatic outline
A_z	-	Average ROC curve area
b	-	Biases
BW	-	Body weight
cm	-	Centimeter
Cn	-	Contrast
Cr	-	Correlation
dB	-	Decibel
dl	-	Deciliter
$d(p_j, Q)$	-	Shortest distance of p_j to contour Q
E	-	Energy
EQ	-	Equality test
F	-	Number of cycle
$GLCM(i,j)$	-	GLCM image
gm	-	Gram
H	-	Homogeneity
I_{IN}	-	Input image
$I_{LAYERED}(i)$	-	Layered image
I_{ORI}	-	Original image
I_{VG}	-	Vector graphic image
$I_{WF}(i,j)$	-	Wiener filtered image
kHz	-	Kilohertz
$K(m,n)$	-	Kurtosis
m	-	Meter

MAP	-	Array
mg	-	Milligram
MHz	-	Megahertz
min	-	Minute
ml	-	Milliliter
n	-	Number of bits
MN	-	Size of image
N_{color}	-	Number of colors
N_{pixel}	-	Number of pixel
N_R	-	Number of pixel in region
N_{shape}	-	Number of shape
p	-	Perimeter
R	-	Roundness test
R_{rank}	-	Region rank
$	-	US Dollar
S_{cr}	-	Serum creatinine
$S(m,n)$	-	Skewness
T_C	-	Threshold
T_T	-	Threshold
$u(i,j)$	-	Discrete image
v	-	Speed
v^2	-	Noise variance
VG2R	-	Vector graphic ratio in 2nd layer
VG3R	-	Vector graphic ratio in 3rd layer
VG4R	-	Vector graphic ratio in 4th layer
w	-	Weight
$x(i,j)$	-	Original image
X_{max}	-	Maximum value of X
X_{min}	-	Minimum value of X
$y(i,j)$	-	Output Image
Y_{max}	-	Maximum value of Y
Y_{min}	-	Minimum value of Y
z	-	Axial resolution

μ	-	Local mean
$\mu(m,n)$	-	Mean
σ^2	-	Local variance
$\sigma^2(m,n)$	-	Variance
θ^0	-	Angle
λ	-	Wavelength

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Nowadays, kidney diseases have become more common than ever, and are rising throughout the world, especially due to the complication of hypertension and type 2 diabetis mellitus [1]. Diseases in kidney may progress to the end stage renal disease (ESRD) which leads to the need of renal replacement therapy (RRT) and hemodialysis, as well as kidney transplants [1]. In Malaysia only, according to 19th Report of the Malaysian Dialysis and Transplant Registry, newly registered dialysis patients continue to increase, from 2375 in 2002 to 5153 in 2010, and at least 5201 in 2011 [2]. Treatments of the diseases are life saving, but demands a long term commitment at a very high cost. Therefore, other than focusing on the treatment itself, early prevention and detection; including urine test, blood test and imaging test of kidney diseases should become a priority. Early detection of kidney diseases allows a more effective and suitable treatment to the patient [3]. In most cases, patients with early stage of kidney disease can receive treatment that can delay or even prevent kidney damage. In addition, early treatment can also prevent many of heart and vascular conditions, which may complicate kidney disease [4]. Besides that, early detection of kidney disease can avoid further unnecessary biopsy and therapy sessions [5, 6].

Currently, there are several types of tests that can be used to diagnose kidney disease. Kidney function can be assessed by performing blood and urine tests.

Blood test is performed to check on the level of the waste product of blood urea nitrogen (BUN) [7] and creatinine [8, 9] while urine tests is performed to measure the level of certain substances in the urine, such as protein [10, 11], glucose, ketones, blood, and other substances. Excessive amount of waste product in blood and related substance in urine indicate that the percentage of kidney function has reduced [7-11]. Besides that, in order to diagnose any disorders that affect the specialized blood vessels of the kidney, kidney biopsy, a procedure for sampling a small portion of kidney tissue, is performed. In addition, imaging tests including ultrasound [16-19], intravenous pyelogram (IVP), computed tomography (CT) [12-15] and magnetic resonance imaging (MRI) [23] scans are performed to get useful information about kidney size, shape and structures.

Among all imaging techniques, the conventional ultrasound is more preferred to be used in the diagnosis and follow-up of patients with kidney diseases [19]. Ultrasound is more affordable compared to the use of MRI technique, besides being widely available, noninvasive, painless, does not require any contrast agent as being used in IVP and does not expose the patient to any radiation compared to using CT scan [16-19]. Diagnostic capability of ultrasound is based on sound waves that travel along the organ and structures, reflected back and appear in a range of hypoechoic to hyperechoic depending on the organ and structure composition [19]. Ultrasound can act as an excellent way to estimate kidney size, shape and position. Ultrasound can provide information about the kidney function, and help in diagnosis of structural abnormalities like cysts, stones, tumors, abscesses, obstructions, fluid collection, or infection within or around kidneys [19-21]. Besides that, the use of Doppler ultrasound may improve sonographic assessment of kidney dysfunction in relation to changes of kidney blood flow [22].

However, the use of ultrasound in current kidney diagnosis also has limitations. A major drawback of this ultrasonography in kidney diagnosis is that this method is very operator dependant [24-30], in terms of locating, measuring, and analyzing the images. Kidney diagnosis using ultrasound depends on the operator skills to locate the kidney in correct position, especially during the measurement of kidney size, or else the measurement would not be accurate. Besides that, the diagnosis also requires well trained and experienced operator/ sonographers in analyzing and interpreting the images, especially when dealing with diseases, as compared to normal kidney, as the kidney with diseases may develop various symptoms and changes in the images [19]. An ultrasound image of kidney may be interpreted differently by different operators and the result is relative to the operator expertise, variations in human perceptions of the images, as well as differences in features used in diagnosis. Other imaging modalities such as CT and MRI allow the radiologists to get and view the stack of images of desired organs in different planes, while patient just lay still on the bed. On the other hand, this US technique requires the operator himself to angle and position the transducer on patients' body in correct position. Different position and angle of the transducer gives different output images thus interpretation of the images will differ. Another limitation is that the ultrasound image itself are affected by the speckle noise with variations of gray level intensities, and the presence of this noise makes analysis of ultrasound images, including locating, measuring, detecting and segmenting of desired structure or parameters become more complex and challenging [24, 30].

Concerning the limited capabilities of ultrasound in kidney diagnosis as mentioned earlier, it is important to develop some alternative approaches to the current system which perhaps can help medical doctors to do an accurate and effective kidney diagnosis. Computerized method, such as computer aided diagnosis (CAD) system can help in minimizing the dependency of the diagnosis on operators, as well as can make the diagnosis become easily reproducible without or with limited variation in result. Development of automatic system in locating, detecting and analyzing the required images can also be alternative solutions to the stated limitations. Therefore, this study will concentrate on improving the current kidney diagnosis method by implementing certain image processing and analysis methods, preferably utilizing algorithm that can performed automatically, which then can be implemented into any computer aided diagnosis (CAD) system for better kidney assessment and classification. However, it should be noted that the research into the use of automatic system or CAD is not toward eliminating the operators themselves, but much more toward providing the operators/ sonographers/ medical experts a second opinion and help them to increase the diagnosis accuracy, reduce the use of other imaging modalities that could be harmful, avoid unnecessary biopsy, and save them time and effort.

1.2 Problem Statement

Ultrasound is often the initial imaging tool used because it can be performed comfortably and safely even when the kidney function is impaired. However, the role of ultrasonography in kidney diseases detection and classification is limited by its dependencies on the expertise of the operators or sonographers to detect, measure, segment and analyze structure of kidney during diagnosis. The use of ultrasound requires the operators to angle and position the transducer correctly to get better view of kidney. Besides that, the ultrasound images may be interpreted differently by different operators and the result is relative to the operators' skills and expertise, variations in human perceptions of the images, as well as differences in features used in diagnosis. Not to mention the limitation in the quality of ultrasound image itself due to the speckle noise. This restriction prevents ultrasonography from taking a prominent role in kidney diagnosis. Hence, this study aims to help and improve the existing ultrasonography for detecting, analysing and classifying the kidney risk by proposing some new approaches on kidney image analysis based on ultrasound image features.

1.3 Objectives

There are few objectives for this research study, including:

1. To develop an algorithm for vector graphic image formation from ultrasound images.
2. To develop new algorithm for automatic region of interest (ROI) generation of kidney images.
3. To develop new algorithm for automatic detection and segmentation of cysts in kidney ultrasound images.

4. To develop new features extraction technique for kidney ultrasound images, and evaluate the experimental result by using artificial neural network for kidney risk classification.

1.4 Scope of Research

Few scopes have been set so that the study is conducted within and heading toward the objectives. This project focuses on the kidney ultrasound images (details of images, machines and operators are in Appendix A) where;

1. For the development and analysis of automatic ROI generation of kidney ultrasound images, normal kidney ultrasound images were collected from the Faculty of Biosciences and Medical Engineering (FBME), UTM Johor Bahru by using Toshiba Aplio MX machine with 3.5MHz transducer.
2. For the development of automatic kidney cysts detection as well as analysis of the kidney ultrasound image features, images were taken from patients at Gelderse Vallei Hospital, Ede, The Netherlands and the diagnosis was made by experts by using ultrasound machine Hitachi Aloka Prosound F75 with transducer 3.5MHz.
3. For automatic detection and segmentation of kidney cysts, only cystic (CD) class of images was used, and for feature extraction and classification, all three classes were used (normal (NR), infectious (BI) and cystic (CD)),
4. Kidney images with multiple diseases (kidney with both CD and BI) were excluded to avoid any similar information between groups.
5. The kidney ultrasound images used in this study were in DICOM (Digital Imaging and Communications in Medicine) format and all necessity care had been taken to preserve the quality of the images.
6. All image processing, and analysis methods applied to the kidney ultrasound images were implemented in MATLAB.

1.5 Thesis Organization

This thesis is divided into five major chapters. Chapter 1 includes an introduction, background, objectives and scope of research. The main purpose is to show the motivation of this research and existing limitations of diagnosing kidney using ultrasound imaging. The chapter is summarized with the novelties and contribution of this thesis and its feasibility. Chapter 2 describes this thesis in terms of its background, history and the related works in greater detail. The focus is on the introduction to kidney, reviews on kidney diagnosis, ultrasound in kidney diagnosis, ultrasound image features, as well as kidney ultrasound image processing. Chapter 3 describes the experimental design and implementation including the research materials, data sources acquisitions and manipulation, image processing and analysis, kidney feature extraction and risk classification. Chapter 4 looks into the results and discussion on the proposed methods, with thorough analysis and validation. Lastly, Chapter 5 provides the conclusion for the system testing and evaluation. It also gives some recommendations for further improvement of the system.

1.6 Contribution of Thesis

Generally, some new improvements have been proposed to help sonographers in performing better and more accurate diagnosis of kidneys using ultrasound. The implemetation of image processing techniques had been explored, together with the analysis and validation of proposed ideas. The contributions of the thesis are;

1. Development of a new vector graphic formation or image vectorization method. Degradation of ultrasound image by speckle noise can complicate the analysis (detection, segmentation, classification, etc.) of the image during diagnosis, as well as restricting the image to be analyzed visually. Important features may not be extracted due to this condition. Development of this method, enables the user to manipulate the images thus helping the user to extract desired features for required objectives.

2. Development of a new algorithm for automatic generation of region of interest (ROI) of the kidney. To the best knowledge of the author, there are no other automatic algorithms available for kidney ultrasound images. This proposed algorithm can be implemented in real time ultrasonography and help sonographer in locating the correct position of the kidney. Besides that, this algorithm can also be used as a pre-processing method before performing further analysis of the images such as segmentation of the kidney.
3. Development of a new approach of automatic detection and segmentation of kidney cyst in ultrasound images, and the result has been fairly compared with other segmentation methods available. Not only it is automatic, this algorithm can also be used to analyze images with multiple cysts, as well as ultrasound image of other cystic organs. Tested of the algorithm to both single and multiple cysts images also gave high accuracy. Compared to other available methods, this method is able to be executed in a very quick time with high accuracy.
4. Development of new algorithm for feature extraction of kidney ultrasound images based on vector graphic image formation. The kidney ultrasound images are classified into three classes (normal, infectious and cystic) using artificial neural network (ANN) which gives a better accuracy compared to using other commonly used features.

This study is strictly technical, and its emphasis was influenced by the opinions of clinical collaborators. Improvements proposed in this study for the purpose of kidney abnormalities detection and classification can reduce manual measurement, improve consistency, reduce human intervention and operator dependency, avoid competency factor and human errors, while producing reliably meaningful images and measurement, so as to support future studies in a clinical setting.

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