Pakistan Journal of Engineering and Technology
ISSN (Print): 2664-2042; ISSN (Online): 2664-2050
Received: 2023-06-24
Accepted: 2023-08-15
https://doi.org/10.51846/vol6iss3pp1-7

PAKJET
Pakistan Journal of Engineering & Technology

Article

Graphical User Interface-Based Detection of Kidney Stones Using Image Segmentation Techniques

Khadijah Ali Shah [1], Zohaib Mushtaq [2], Syed Muddasir Hussain [1], and Muhammad Haris Aziz [3]

[1] Department of Biomedical Engineering, Riphah International University, Islamabad, Pakistan
[2] Department of Electrical Engineering, University of Sargodha, Sargodha, Pakistan
[3] Department of Mechanical Engineering, University of Sargodha, Sargodha, Pakistan
* Correspondence: Zohaib Mushtaq (zohaib.mushtaq@uos.edu.pk)

Abstract: The exponential increase in detrimental surroundings and unhealthy nourishments is causing various health issues in humans. The most destructive effect of such lifestyles is on the kidneys, which cause many kidney diseases, and the most common among them are kidney stones. Kidney stones are a regular but life-threatening disease as they mostly remain unrecognized at the initial stages, leading to an increased threat of end-stage kidney failure. Due to the high recurring rate, Medical Imaging technologies are of paramount importance in detecting this serious public health threat worldwide. This research paper provides a Graphical User Interface for the detection of kidney stones that enables ease of understanding and point-and-click control of the algorithm in MATLAB. The proposed work uses CT scan images to explore image processing techniques due to their reliability and regularity. The algorithm enhances kidney stone screening by improving image quality and focusing on the region of interest. This study highlights the best solutions of imaging techniques to resolve problems like grainy pixels, low-resolution images, and the inaccurate detection of kidney stones due to size and resemblance with nearby parts. All this begins with examining the medical imaging slices from the body area, which later undergoes preprocessing, segmentation, and boundary detection techniques. To check the accuracy of the algorithm, 12 features were extracted using GLCM. Finally, the obtained features were classified using the Classification Designer App in MATLAB. An accuracy of 99.2% was acquired using Ensemble Classifiers. Also, for further progress in the detection of kidney stones in the future, an AI model can be trained so that it can deal with images having different thresholds for better management of the disease.

Keywords: Computerized Tomography, Kidney Images, Kidney Stones, Renal Calculi, Segmentation, Thresholding Image Processing

1. Introduction

1.1. Background and Motivation

The outrage of the global crisis of unhealthy environments and lifestyles has rampaged the well-being of mortals at an increasing rate. Globally, these have led to various kidney abnormalities that include cysts, hydronephrosis, obstructive uropathy, congenital abnormalities, urinary tumors, and commonly nephrolithiasis.

Nephrolithiasis, a frequent kind of urological disease, causes kidney stones. Kidney stones are developed inside the kidneys by a solid mass formation. These are also referred to as renal calculi. Renal stones have different structures and variable sizes ranging from ping-pong balls, and chickpeas to grains of sand. They can be localized along the urinary tract whether in the renal papilla, calyx, ureter, or urinary bladder, and can be identified accordingly such as Calyceal stone, Renal pelvic stone, Staghorn stone, Upper ureteral stone, Mid-ureteral stone, and bladder stone. According to a recent study, about 14.8% of the world population is facing renal stone disease [1]. The growing trend of the increase in Kidney Stone disease also has a frequent recurrence rate of 10% after one year, 50% over the course of five to ten years, and 75% after twenty years [2]. Kidney stone disease may cause Hematuria, nausea, pain, urinary tract infections, Renal colic, which is the blockage of urine in the kidney, etc. It is a common urological disorder that may lead to other diseases such as diabetes, blood pressure issues, and a 2 to 3% threat of end-stage kidney failure [3].

According to recent reports, the rate of renal calculi is increasing worldwide in both flourishing and thriving countries. The urinary stone disease affects 9% of individuals in the United States, and every year, about 600,000 Americans suffer from this disease. In Asia, the kidney stone prevalence rate is 1 in 12 people, and almost 50% of them ultimately suffer from renal failure [3]. The increasing prevalence and reoccurrence rate of the disease affects all ages, genders, and nationalities. For the years 2015–2016, the NHANES study indicates a 13.0% prevalence in men and a 9.8% prevalence in women, with people over 80 years having the highest frequency [4].

Various medical imaging techniques are used for the screening of renal calculi but the most common are Ultrasound and Computed tomography. Due to low-resolution medical image quality, Kidney stone detection is challenging which makes human and machine interpretation quite difficult. However, computerized tomography (CT) imaging is the most reliable and commonly used for renal stone detection as it provides important details about the renal stones' placement, structure, and sizes which are necessary for diagnosis and treatment [5]. CT scan imaging merges a successive arrangement of X-ray images at different angles of the body. Through computer processing, it offers three-dimensional cross-sectional images (slices) of the target region inside the body. CT technology is crucial for both doctors and patients since it is convenient, more detailed, and effective at detecting kidney stones [6].

The applications for technological progress in the area of medical imaging currently acknowledge the need to make improvements. The algorithm's effectiveness depends on its ability to compute the number of stones, their area, and their placement. Thus, the aim of this research is to effectively detect kidney stones by using image processing techniques and also to provide potential solutions for future endeavors.

1.2. Literature Review

This section gives a summary of the numerous kidney stone screening methods that are used on CT images. The identification of kidney stones in a human body is quite challenging, because of the tissues and bones in its close proximity. Therefore, many researchers have contributed to improving the classification techniques to detect kidney stones most efficiently.

In this research [5], three segmentation methods i.e. Edge-based Segmentation, Watershed-based Segmentation, and Threshold Segmentation were investigated using CT images. They concluded that the Threshold Segmentation technique is best for binary images and that Watershed Segmentation is appropriate when more dimensions are involved. Moreover, T.Shah et. al developed a renal stone detection algorithm using Threshold Segmentation and Gaussian Filters and tested it on 40 CT images acquiring an accuracy of 90% [7]. On the other hand, S. Ebrahimi used threshold segmentation using Gamma Adjustment to develop the algorithm for kidney stone detection and obtained 84.61% accurate results on 39 individuals having Kidney stones [8]. Later, N.Thein et. al. designed three algorithms each for 3 different parameters which are intensity, size, and location of stones using threshold segmentation. They analyzed them for CT scans images from 30 patients with kidney stones and acquired an accuracy of 95.24% [9]. Furthermore, the researchers used median filters and morphological operations on ultrasound images to detect the region of interest and obtained an accuracy of 92.57% [10]. Similarly, P. T. Akkasaligar et. al developed a system for renal stone detection by using CT images of 50 patients. They used Level Set Segmentation and Region-based Segmentation to detect ROI using Centroid and Area [11]. Thus, these researches have played an important role to wave the path in the development of improved algorithm for efficient detection.

1.3. Contribution

The correct identification of anatomical characteristics is crucial for the management and surgical treatment. The idea of this paper is therefore to effectively detect kidney stones by using automatic renal CT image processing techniques. It presents an efficient AI algorithm and analyzes it on 370 CT images with 300 Kidney Stone images and 70 Normal images, acquiring an accuracy of 99.2%. This research also provides a Graphical User Interface for better visualization.

1.4. Paper Organization

A thorough overview of the subject matter has established the framework for subsequent sections. The following research paper is organized as follows: the materials and methods, followed by the results and discussion section. Finally, the work ends with a conclusion.

2. Materials and Methods

With the rapid rise in kidney diseases, the need to efficiently link the healthcare sector with technology has become a necessity. The basic representation of the methodology is to segment the target object, i.e., the kidney stones, by using image processing and analyses to determine its presence, area, and location, as illustrated in Fig. 1.

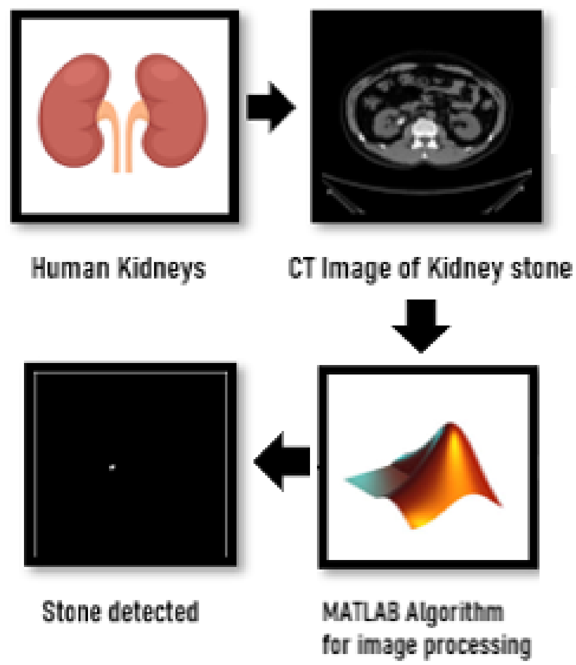

Figure 1. The basic representation of the proposed work.

The identification of renal stones begins with the selection of the dataset, then preprocessing of the image using a median filter used to remove noise from the image, then the region of interest is selected by using windowing. The masks are applied to the CT image to get the object of interest i.e. kidney stones. After this morphological operation is applied to wash away the final image. Then the boundary detection of the stones is done to find their features, including their quantity, size, and placement. The sections below in Fig. 2 illustrate the methodology of the algorithm in the mentioned area.

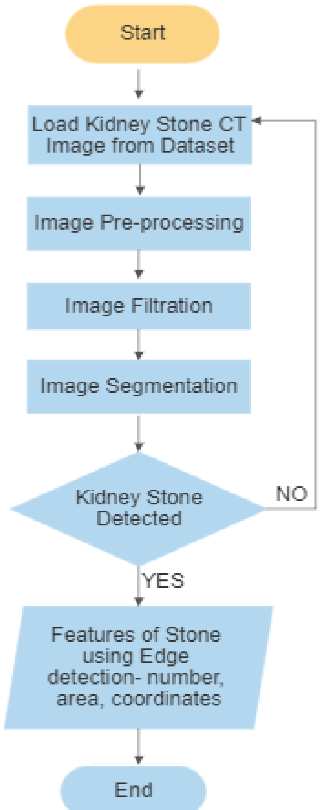

Figure 2. The proposed methodology for the algorithm designing presented in this research.

2.1. Dataset Used for Algorithm

The first step is the selection of the dataset of CT scan kidney images. An online dataset of symptomatic patients having kidney stones and asymptomatic/healthy individuals is chosen from an Open-Access Database [12]. The proposed algorithm of image processing in MATLAB is applied to 300 CT scan images of renal stone patients from the dataset and 70 healthy patients. The diagnoses are done on them to verify the presence or absence of kidney stones.

2.2. Loading and Preprocessing of Dataset

The original CT Image is loaded and its preprocessing is done to enhance the image. It is important to remove noise and suppress artifacts as most medical images have poor resolution quality and contrast [13]. The original image is converted into grayscale and then into binary with a specified threshold. Binarization allows the segmentation of the foreground (abdomen) with white color and the background with black color. There are two values of the pixel in binary digital images: 1 and 0 [9]. The segmentation procedure is simplified as a result.

2.3. Bones Removal and Noise Filtering

The Spine and connected bones disrupted the correct detection of stones and it is a necessity to remove them. The density and area of these bones were extracted using the 'region props' command and then subtracted it from the binary image. After this filtering of the image is done to extract the desired image features. The proposed algorithm uses a median filter of a specified square matrix. The noise makes it difficult to accurately detect stones, which might injure kidney tissues during operation. So, to remove such noise image processing and the proper location of the kidney stone are necessary.

2.4. Image Segmentation via Designed Algorithm

Segmentation is utilized to locate the area of interest by extracting the features of the image pixels [14]. Different Segmentation methods can be applied according to different researchers' methodologies. However, this research paper performs segmentation by partitioning the image into multiple segments and extracting features from the kidney images that can locate the kidney stone area. To focus on the region of interest, where the kidneys are found, the MATLAB function "roiploy" is used to specify the region of interest by generating a mask to be applied to the actual picture to detect the target object. This function is applied to both kidneys.

2.5. Identification and Boundary Detection of the Kidney Stones

After segmentation, the masks for the right and left kidneys are applied to the filtered image individually. If there are any white pixels on the display, they represent part of the kidney stone. In order to locate the stones, all irrelevant regions are eliminated. As a result, both the number of stones and the area each stone covers are determined. It indicates the number of pixels in the stone-identified region. Several non-connected components are around [15]. The masked images of both the right and kidney are then added using OR logic. Therefore, this counts the number of renal calculi, their location, and size.

2.6. Graphical User Interface

This was implemented on a Graphical user interface (GUI) in MATLAB to make an app for kidney detection that can provide point-and-click control of the MI algorithm and eliminates the need for others to learn the code.

2.7. Feature Extraction

This paper extracts the statistical and texture features by gray-level co-occurrence matrix GLCM. These are low-level characteristics that describe an image's contents, such as quantifying an image's perceived texture. Statistics come in three different orders, depending on how many intensity points are present in an image. Though theoretically feasible, implementation of higher-order statistics is impossible due to computational cost. Information regarding the structural organization of surfaces and their interactions with their surroundings is contained in texture features. This paper extracts 12 features in total. Out of these, five are GLCM-based texture features which are Contrast, Correlation, Energy, Homogeneity, and Entropy shown in Table 1. The remaining eight are statistical features including Mean, Standard Deviation, RMS, Variance, Smoothness, Kurtosis, and Skewness. The features are extracted from 300 Kidney Stone scans and 70 healthy kidney scans. These 12 features for 370 scans were converted into an excel sheet.

Table 1. GLCM features extracted for the classification.

GLCM Features	Formulas
Contrast	$\sum_{i,j=0}^{N-1} Qij(i-j)^2$
Correlation	$\sum_{i,j=0}^{N-1} Qij\left(\frac{(i-\mu)(j-\mu)}{\theta^2}\right)$
Energy	$\sum_{i,j=0}^{N-1} (Qij)^2$
Homogeneity	$\sum_{i,j=0}^{N-1} Qij\left(\frac{(i-\mu)(j-\mu)}{(i-j)^2}\right)$
Entropy	$\sum_{i,j=0}^{N-1} -ln\,(Qij)\,Qij$

Qij = (i, j) element of normalized GLCM matrix,
μ = mean of GLCM matrix;

2.8. Classifier Implementation

The ‘Classification Learner App’, a MATLAB application was used to classify the Normal Kidney Images and Kidney Stone Images. Different classifiers were trained for 5-fold Cross Validation in the application i.e., KNN Classifiers, Ensemble Classifiers, and Support Vector Machine Classifiers [16].

3. Results and Discussions

This research designs an algorithm for the accurate identification of Renal Calculi as represented by the results. The following subsections describe the results of the stepwise designed algorithm, the Graphical User Interface, the accuracies of different classifiers, the confusion matrix outcomes, and a comparison of this study with previous research, respectively.

3.1. Results of the Designed Algorithm

The first result is of preprocessing, after the loading of the CT image from the dataset, as shown in Fig. 3. The original image is transformed into a grayscale image, which is then further processed into a binary image also known as black and white image as it has two color variations.

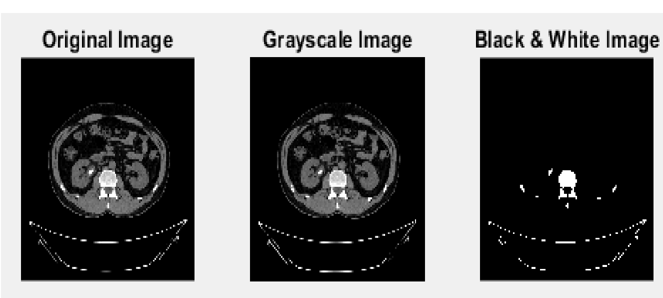

Figure 3. Loading and preprocessing of CT image.

After preprocessing, the CT image is segmented and filtered by applying a square matrix median filter to it. This is done to remove noise and improve contrast, the results of which are displayed in Fig. 4.

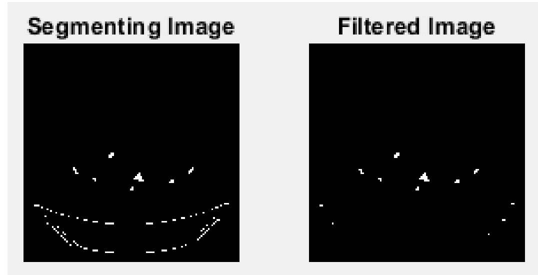

Figure 4. Segmented image and the median filtered image.

The image segmentation is done via the designed algorithm by focusing only on the region of interest i.e., the area of kidneys and extracting the features in it. Thus, the result presents two masks created for the right and left kidneys by specifying the size and position of both masks, as illustrated in Fig. 5. This is done in order to specify the region of interest.

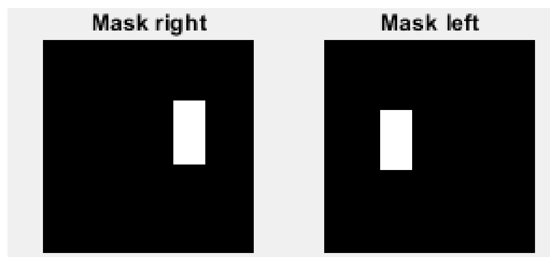

Figure 5. The masks specifying the regions of interest.

The stones are then identified by applying the masks to the filtered image and then the boundary of the identified stone is also determined, the outturn of which can be seen in Fig. 6. The boundary detected for each of the identified stones gives a count of the number of renal calculi, their location, and size.

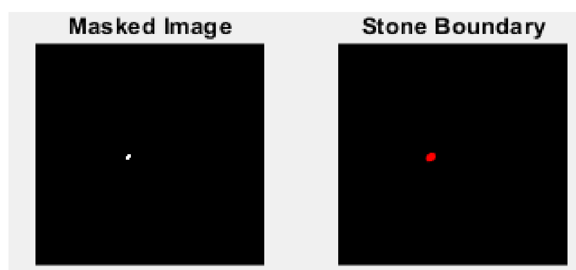

Figure 6. The stone and its boundary detection.

3.2. Results of Graphical User Interface

After the appropriate results for all the steps identified in the methodology, a Graphical user interface (GUI) is developed in MATLAB as shown in Figs. 7 and 8. This paper thus defines a layout of the app for the “Detection of Kidney Stones”.

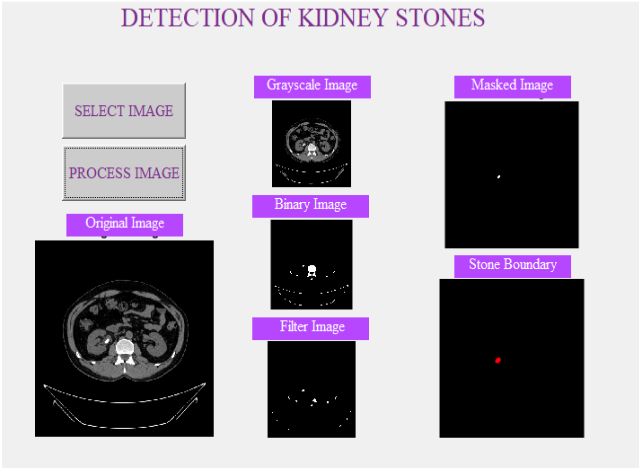

Figure 7. The GUI of kidney stone detection in MATLAB applied on kidney stone scan.

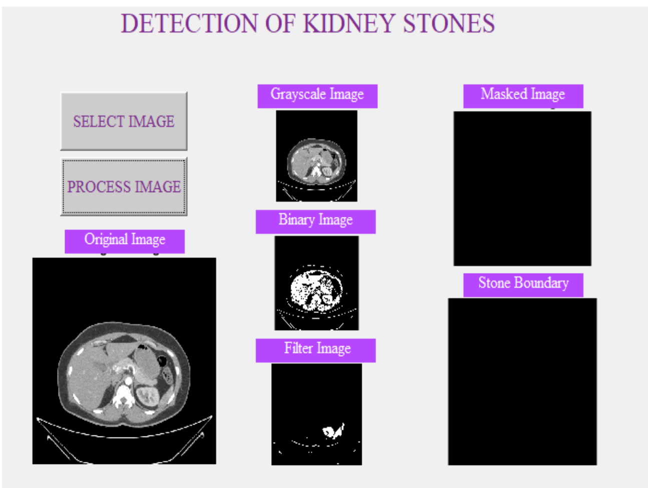

Figure 8. The GUI of kidney stone detection in MATLAB applied on healthy kidney scan.

3.3. Result of Confusion Matrix for the Best Classifiers

A confusion matrix or an error matrix, is a particular table format used for statistical classification that enables the visualization of an algorithm's performance [17]. The Description of the confusion matrix is given in Fig. 9.

		Predicted Condition	
	Total Population (P+N)	Positive (PP)	Negative (PN)
Actual Condition	Positive(P)	True Positive (TP)	False Negative (FN)
	Negative(N)	False Positive (FP)	True Negative (TN)

Figure 9. The description of the confusion matrix.

The Confusion Matrix was also obtained using the Classification Learner App. The Confusion Matrix for the best accuracy classifier types are obtained. Figs. 10, 11 and 12 shows confusion matrix for Linear SVM, Weighted KNN and Subspace KNN where 339 classes, 338 classes and 341 classes from a total of 370 were correctly classified respectively.

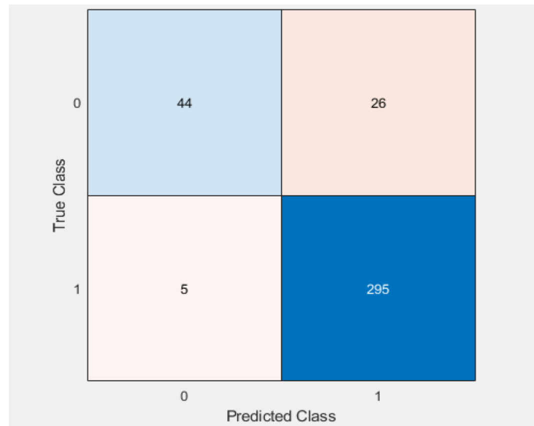

Figure 10. The confusion matrix for SVM classifier.

Figure 11. The confusion matrix for medium KNN classifier.

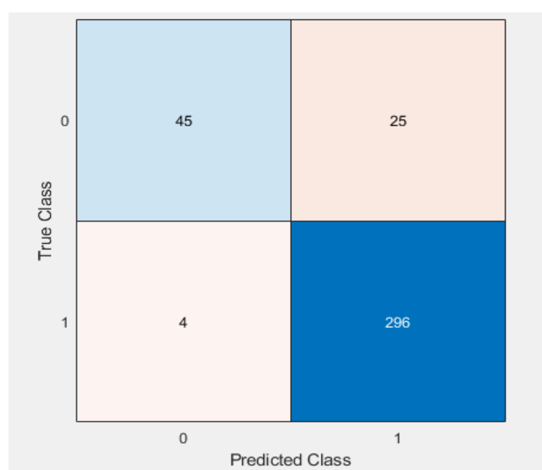

Figure 12. Confusion matrix for Ensemble classifier.

3.4. Results of Classifiers using GLCM Features

The Classification Learner Application was used in MATLAB Software to find the results of the designed algorithm are shown in Table 2. The 5-fold cross-validation was used to obtain accurate results. All of the trained classifiers provided a very good accuracy above 90%. The best accuracy has been achieved using the Ensemble classifier named "RUS-Boosted Trees" which is 99.2%. The other classifiers trained are K-nearest neighbor classifiers and SVM classifiers.

Table 2. The accuracies of different classifiers using the Classification Learner App.

Classifiers Type	Classifiers Name	Classifiers Accuracy
SVM Classifiers	Linear SVM	91.6%
	Quadratic SVM	91.4%
	Cubic SVM	91.2%
	Fine Gaussian SVM	91.4%
	Medium Gaussian SVM	91.6%
	Coarse Gaussian SVM	90.3%
KNN Classifiers	Fine KNN	90.8%
	Medium KNN	91.4%
	Coarse KNN	81.1%
	Cosine KNN	91.1%
	Cubic KNN	90.8%
	Weighted KNN	92.2%
Ensemble Classifiers	Bagged Trees	98.9%
	Boosted Trees	98.9%
	Subspace Discriminant	96.8%
	Subspace KNN	92.2%
	RUSBoosted Trees	99.2%

3.5. Comparison of the Achieved Accuracy with Previous Studies

The algorithm's effectiveness depends on its ability to compute the number of stones, their area, and their placement. The comparison of this research is made with the previous studies in relation to the main segmentation technique, Patients/ Images involved in the study and the accuracy of the algorithm designed as shown in Table 3. Therefore, this comparison proves that this research provides the best accuracy with the highest number of images so far.

Table 3. Comparison of this study with previous studies.

Research Papers	Main Methodology	Patients Involved	Accuracy Obtained
T. Shah and S. Kadge [7]	Threshold Segmentation & Gaussian Filters	40 Persons	90%
S. Ebrahimi and V. Y. Mariano [8]	Threshold Segmentation is done using Gamma Adjustment	39 Persons	84.61%
N. Thein, H. A. Nugroho, T. B. Adji and K. Hamamoto [9]	Intensity-based Thresholding, Area based Thresholding, and Location-based thresholding	30 Persons	95.24%
M. Kavitha, 2 Kiruba. N [18]	Segmentation and morphological analysis, Fuzzy means Classification	20 samples	95.7%
This Research	Region-based Thresholding	370 Persons	99.2%

4. Conclusion

In this study, an efficient methodology is adapted for the detection of kidney stones and its GUI has been developed. It covers the implementation of different segmentation methods and the analysis of different imaging techniques. Moreover, there are many opportunities in the future such as deploying new technologies for a bigger pool of advancements and developing protocols and procedures for adapting technologies more efficiently. Additionally, by creating ease and providing better treatment to the patients. Moreover, different advancements in AI model development can create potential improvements in kidney detection by selecting different thresholds thus providing a greater cause to serve humanity.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] K. Stamatelou and D. S. Goldfarb, "Epidemiology of Kidney Stones," MDPI, https://www.mdpi.com/2227-9032/11/3/424

[2] A. Sohgaura and P. Bigoniya, "A review on epidemiology and etiology of renal stone," Science Alert, https://scialert.net/fulltext/?doi=ajdd.2017.54.62

[3] T. Alelign and B. Petros, "Kidney Stone Disease: An Update on Current Concepts," Adv. *Urol.*, vol. 2018, 2018, doi: 10.1155/2018/3068365.

[4] S. R. Khan et al., "Kidney stones," Nature reviews. Disease primers, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5685519/

[5] M. M. Abu-Faraj and M. Zubi, "Analysis and implementation of kidney stones detection by applying segmentation techniques on computerized tomography scans," Ital. J. Pure Appl. Math., vol. 43, 2020.

[6] C. J. McCarthy, V. Baliyan, H. Kordbacheh, Z. Sajjad, D. Sahani, and A. Kambadakone, "Radiology of renal stone disease," Int. J. Surg., vol. 36, no. PD, pp. 638–646, 2016, doi: 10.1016/j.ijsu.2016.10.045.

[7] T. Shah and S. Kadge, "Analysis and Identification of Renal Calculi in Computed Tomography Images," 2019 International Conference on Nascent Technologies in Engineering (ICNTE), 2019, pp. 1-4, doi: 10.1109/ICNTE44896.2019.8945877.

[8] S. Ebrahimi and V. Y. Mariano, "Image Quality Improvement in Kidney Stone Detection on Computed Tomography Images," J. Image Graph., vol. 3, no. 1, pp. 40–46, 2015, doi: 10.18178/joig.3.1.40-46.

[9] N. Thein, H. A. Nugroho, T. B. Adji and K. Hamamoto, "An image preprocessing method for kidney stone segmentation in CT scan images," 2018 International Conference on Computer Engineering, Network and Intelligent Multimedia (CENIM), 2018, pp. 147-150, doi: 10.1109/CENIM.2018.8710933.

[10] T. Vineela, R. V. G. L. Akhila, T. Anusha, Y. Nandini, and S. Bindu, "Kidney Stone Analysis Using Digital Image Processing," no. 3, pp. 3–6, 2020.

[11] P. T. Akkasaligar and S. Biradar, "Automatic Segmentation and Analysis of Renal Calculi in Medical Ultrasound Images," *Pattern Recognition and Image Analysis*, vol. 30, no. 4, pp. 748–756, Oct. 2020, doi: https://doi.org/10.1134/s1054661820040021.

[12] M. Islam, *Ct Kidney Dataset: Normal-cyst-tumor and stone*, vol. 02,2021.Available at: https://www.kaggle.com/datasets/nazmul0087/ct-kidney-dataset-normal-cyst-tumor-and-stone.

[13] R. C. Gonzalez and R. E. Woods, Digital Image Processing, New York, NY, USA:Pearson, 2007.

[14] P. T. Akkasaligar, S. Biradar and V. Kumbar, "Kidney stone detection in computed tomography images," *2017 International Conference on Smart Technologies For Smart Nation (SmartTechCon)*, Bengaluru, India, 2017, pp. 353-356.

[15] G. R. R, R. Cyriac, D. Pamela, P. Manimegalai and P. Angel Michael, "Renal Calculi Detection using Image Processing," *2022 Second*

International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT), Bhilai, India, 2022, pp. 1-4.

[16] J. Verma, M. Nath, P. Tripathi and K. K. Saini, "Analysis and identification of kidney stone using Kth nearest neighbour (KNN) and support vector machine (SVM) classification techniques", *Pattern Recognition and Image Analysis*, vol. 27, 2017.

[17] An introduction to ROC analysis - ELTE https://people.inf.elte.hu/kiss/11dwhdm/roc.pdf.

[18] M. Kavitha, "Detection of Kidney Stones Using Image Processing," International Journal of Research Publication and Reviews Journal homepage: www.ijrpr.com, vol. 3, pp. 17–25, 2022, Accessed: Aug. 17, 2023. [Online]. Available: https://ijrpr.com/uploads/V3ISSUE9/IJRPR6853.pdf