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A Literature Review on Various Algorithms Used During Kidney Stone Detection Process

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***Abstract*—Kidney stone also known as renal calculi which are solid masses made up of crystals. It is very important to detect the exact and accurate position of kidney stone for surgical operations. Since the ultrasound images contain speckle noise, therefore it is difficult to detect the kidney stone manually and hence it is required to use automated techniques in detection of kidney stones in ultrasound images. This paper presents the literature review and comparative study of various algorithms available in the existing literature for kidney stone detection in human bodies.**

Keywords*—*Kidney stone detection; noise filtering techniques using Matlab; ultrasound de-noising; speckle noise removal.

I. INTRODUCTION

Kidney is a bean shaped organ and is present one on each side of the spine. It lies in the retroperitoneal position at a slightly oblique angle. The main function of the kidney is to regulate the balance of electrolytes in the blood, along with maintaining pH homeostasis. Formation of stones, blockage of urine, congenital anomalies, cysts, and cancerous cells are the reasons which lead to kidney abnormalities.

Kidney stone is a solid concretion or crystal formed in kidneys from dietary minerals in urine. In order to get rid of this painful disorder the kidney stone is diagnosed through ultrasound images and then removed through surgical processes like breaking up of stone into smaller pieces, which then pass through urinary tract. If the size of stone grows to at least 3 millimeters, then they can block the ureter. This causes a lot of pain mostly in the back lower and it may radiate to groin. Classification of urinary stone is done based upon their location in the kidney (nephrolithiasis), ureter (ureterolithiasis), or bladder (cystolithiasis), or by their chemical composition (struvite, calcium-containing, uric acid or other compounds).

Figure 1 depicts the location of kidney stone in human body. The stone may be present inside minor and major calyces of the kidney or in the ureter. This paper provides deep insight into various kidney stone detection techniques available in the existing literature.

In medical imaging modalities, ultrasonography is used because it is versatile, portable, does not use ionizing radiations and is relatively of low cost. The big disadvantage of ultrasound image is that it consists of poor quality of images that has low contrast and multiplicative speckle noise thus making it a challenging task for detection of kidney stones. Speckle noise present in the image degrades its quality which thereby affects the interpretation and diagnosis made by specialist.

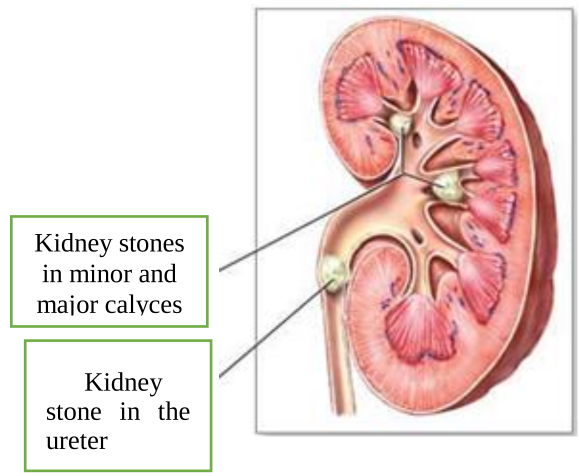

Fig. 1. Stone Location in Kidney

Thus to produce the efficient stone detection system, speckle filtering is one of the foremost and important step in the automated detection. This can reduce erroneous detection which may occur due to knowledge variation of judging specialist. Preprocessing is then followed by segmentation and morphological analysis to detect the stone automatically.

Many researchers have contributed in the field of kidney stone detection by presenting various algorithms to detect the stone in the kidney from MRI images. Some researchers emphasize on producing noise free image for segmentation. Some emphasized on strong and efficient segmentation for accurate detection of stone. Once the image enhancement and noise reduction of the ultrasound image is done then the region of interest is obtained from the image. Akkasaligar et al. [1] states that Gaussian Low Pass Filter is the most optimal filter in differentiating cystic and normal kidney images while Hafizah et al. [2] states that choosing Gaussian Low Pass Filter at threshold value 0.7 to generate true kidney ROI.

Many researchers have contributed by presenting different algorithms in this field. Saini et al. [3] has stated that OTSU'S method is used for image segmentation and optimal global thresholding. Raja et al. [4] proposed that most fascinating pixel can be found by K-means clustering and Contour based Region selection process.

The main contribution of this paper is that the detailed process of detecting a kidney stone using ultrasound images is give. This paper also discusses various kidney stone detection techniques available in the existing literature with their advantages and disadvantages. Further, comparative study of various existing kidney stone detection techniques on the basis of different evaluation parameters used in the field of kidney stone detection is provided in this paper.

The rest of the paper has been organized as follows: In section II the steps for detection of kidney stone are given. In section III the parameters taken for evaluation are explained and a comparative study is made based on these parameters. In section IV Literature Review is given which states important points made by different authors in their research papers. Section V contains comparative study of parameters such as PSNR and SNR which help in improving the accuracy of kidney stone detection. Lastly, section VI concludes the result obtained after literature review and comparative study done in this paper.

II. STEPS FOR DETECTION OF KIDNEY STONE

This section gives the detailed process of kidney stone detection from ultrasound images. This process involves many important steps which are given as follows. The first step in the process of kidney stone detection is the image pre-processing which is then followed by image segmentation and morphological analysis.

Image Pre-processing: Pre-processing is the first step of image processing. The reliability of optical inspection is increased by image preprocessing. Noise removal using filter operations helps in intensifying or reducing specific image details thus making evaluation of the image easier and faster. It involves user specific filtering, image enhancement, edge filtering.

Ultrasound images consist of a lot of speckle noise. Due to this noise there is huge disturbance in the ultrasonic image. This disturbance leads to inaccurate detection of the stone which can cause harm to kidney tissues during surgery. So, de-speckling of noise is a very crucial step of image pre-processing which improves the quality of image and enhances the information of required content.

Image Segmentation: Image segmentation is the process of dividing a digital image into sets of pixels which are also known as super pixels. Augustine et al. [5] states that for effective segmentation, ROI model is used to detect the abnormal region based on clusters and centroids. This step involves clustering algorithm which categorize the input data points into different categories depending on their inherent distance from each other. It is used in detecting the region of interest, i.e. the specific area where most of the analysis has to be done.

Morphological Analysis: Morphing is the process of transforming object shapes from one form to another. In order to smoothen the region of interest morphological operations are applied. Morphological operations process the images depending on shapes while using structuring element. The process of smoothening is done by removing the unwanted pixels from the outside region of region of interest. Morphological operations include dilation and erosion of image.

Figure 2 depicts a flowchart that forms the basis for kidney stone detection in ultrasound images.

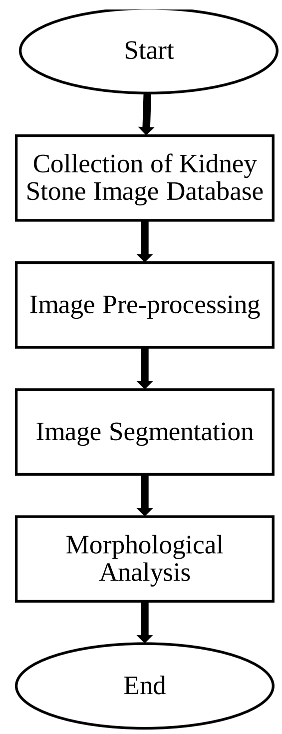

Fig. 2. Flowchart for detection of kidney stone

III. EVALUATION PARAMETERS

This section provides an overview of the evaluation parameters that can be used for evaluating the efficiency and correctness of the designed kidney stone detection algorithm. Various parameters which can be used to calculate the accuracy of a kidney stone detection algorithm using MRI images are given as below:

Peak Signal to Noise Ratio (PSNR): It is the ratio of "maximum possible value (power)" and distorting noise power. It figures out the lossless and lossy compression after reconstruction. The formula of PSNR is given in equation (1).

$$PSNR = \log \frac{[2^n - 1]^2}{MSE} = \frac{10 \log 255^2}{MSE} \quad (1)$$

Where,

n represents the nth frame.

MSE represents Mean Square Error.

PSNR represents Peak Signal Ratio

A. Signal to Noise Ratio (SNR)*:* It is a prevalent way to figure out the suppression in the noise in multiplicative noise case in coherent imaging. The formula to evaluate SNR is given in equation (2).

$$SNR = 10\, log_{10} \frac{\Sigma (x_{j,k})^2}{\Sigma (x'_{j,k} - x_{j,k})^2} \tag{2}$$

Where,

$X_{j,k}$ represents original image.

$X'_{j,k}$ represents noisy image.

B. Mean Square Error (MSE): It computes the accuracy of each input in the sample recovers with the channel output. It is highly dependent on the scaling intensity of the image. The formula of MSE is given in equation (3).

$$MSE = \frac{1}{MN} \sum_{J=1}^{M} \sum_{k=1}^{N} \left(X_{J,k} - X'_{J,k} \right) \tag{3}$$

Where,

$X_{j,k}$ represents original image.

$X'_{j,k}$ represents noisy image.

C. Mean Absolute Error (MAE): It is the measure of the mean of the absolute errors. The absolute error is the absolute value of the difference between the forecasted value and the actual value. The formula of MAE is given in equation (4).

$$MAE = \frac{1}{n} \sum_{j=1}^{n} \mathrm{mod}\left(y_j - \hat{y}_j \right) \tag{4}$$

Where,

y_j represents the prediction.

$\hat{y}_j$ represents true value.

The parameters given above are being used in the field of kidney stone detection. According to the existing standards, PSNR value greater than 40dB is an indication of effective kidney stone detection. In order to represent the effectiveness of the detected area, the value of MSE should be closer to 0 for a kidney stone detection algorithm to be accurate.

IV. LITERATURE REVIEW

This section provides a detailed overview of various existing kidney stone detection techniques using various images. Kidney stone detection in a human body is tedious task, as if wrongly detected this can lead to life threat. So, in order to eliminate or reduce inaccurate detection of kidney stones many of the researchers have given their contribution by providing efficient kidney stone detection algorithms. The automation of kidney stone detection can reduce or approximately eliminate manual erroneous detection. This can help in better and accurate cure of the problem and can save human lives. Thus, it has a direct impact on the society.

Mallala et al. [6] investigated a C-arm tomographic technique in their paper to develop three-dimensional structure of kidney. The result of their experiments showed the ability to develop volume information for kidney stone detection but Computerized Tomography (C.T.) scans of the kidney have greater exposure to radiations than the regular exposure to regular X-ray radiations, particularly in the case of patients who need repeated scanning and children who have less developed bones. Therefore, Sadeghi et al. [7] discussed the radiographic method, which use X-ray films to diagnose stone faster and more accurately. The result of their paper shows almost 90% of urethral stones as dark and obscure. Therefore, the disadvantage is that precise and accurate detection is limited. Furthermore, uric acid stones could not be observed and smaller stones are out of the field of view. Hence kidney stone detection is done in an improved method by using Doppler imaging sequence by Cunitz et al. [8]. Their paper quotes that ultrasound is much better than computed tomography (CT) and KUB (Kidney, Ureter, and bladder) X-ray and it can also prevent from good amount of exposure from radiations. They proposed a method to improve specificity and sensitivity of ultrasound by color Doppler imaging but it produced twinkling effect because of the many bubbles caged in crevices and cracks of the kidney stone. Further the research shows that involvement of filtering techniques in ultrasound images is crucial for detection of kidney stones.

Sun et al. [9] designed a rotational sono-probe that could take sonographic images of four equally separated angles with respect to an axis that is fixed and rotating. Calculation of renal volume manually is time consuming and unreliable. Their method is performed by minimizing some energy functions. Therefore, their automated method of calculating renal stone is precise and accurate as compared to that done manually. This three-dimensional analysis is further used by Marsousi et al. [10] to improve kidney stone detection using automated methods. Their method automatically diagnoses and segment kidneys in “three-dimensional abdominal ultrasound images”.

Works of Tsao et al. [11] shows that detection of accurate position of kidney stone is very important for extracorporeal shock waves lithotripsy (ESWL). Since it uses shock waves to focus on renal stone in real time, the miss-hit of shockwave can cause damage or trauma to the tissues. Their research shows that ultrasonic images contain speckle noise which needs to be removed. Another research by Sapozhnikov et al. [12] shows that inertial cavities of stone play a crucial role in ESWL. The cavitation in stone may cause tissue injury during shockwave lithotripsy. The result of their paper shows that size and focal location calculated in vivo can be more accurate by using high intensity focused ultrasound (HIFU). While Singh et al. [13] have discussed ultrasonic parameters of renal calculi in their paper. They calculated ultrasonic velocity attenuation, impedance, dynamic module of elasticity, transmittance and coefficient of reflectance in vivo for various samples of renal calculi. These parameters help in designing a better ultrasonic lithotripter. The accuracy of the method used in their investigation is closely ±1%.

Rahman et al. [14] proposed reduction of speckle noise and segmentation of ultrasonic kidney images not only improves kidney stone detection but also enhances the quality of image. Furthermore, Vishwanath et al. [15] extracted some energy levels that give a hint of the presence of kidney stone in a specific location and then their paper applies Multilayer Perception (MP) and Back Propagation (BP) to increase the accuracy of type of stone detected to 98.8%.

V. COMPARATIVE STUDY

This section of this paper gives a comparative analysis based on some evaluation parameters that are used in the detection of kidney stone. The parameters used in this paper are namely SNR and PSNR. SNR stands for Signal to Noise Ratio and PSNR stands for Peak Signal to Noise Ratio. SNR is a prevalent way in order to figure out the suppression in the noise in case of multiplicative noise in coherent imaging. PSNR helps in figuring out the lossless and lossy compression that is left after reconstruction. Table I give a comparative analysis of different techniques stated by different authors in various research papers.

TABLE I. **COMPARATIVE STUDY OF VARIOUS EXISTING ALGORITHMS**

Technique	*PSNR*	*MSE*
Gupta et al. [16]	64.366	0.0247
H. et al. [17]	24.0729	254.56
Pathak et al. [18]	20.252	NR
Nicolae et al. [19]	31.6108	2.0958
B. et al. [20]	72.5295	46.0431 (Median)

a. *NR: Not Reported

VI. CONCLUSION

A preliminary study of detection of kidney stone using ultrasound images has been done in this paper. From the above Literature review and comparative study it can be concluded that kidney stone detection is done better in ultrasound images as compared to C.T. scan and X-ray images. Even ultrasound images need further pre-processing such as removal of speckle noise and then segmentation and morphing. In future, the emphasis will be to design and implement an algorithm which can detect kidney stone with a very high accuracy.

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