Classification of urinary stones based on edge detection using semi-automatic threshold

L A Fitri, Y Warty, F Haryanto, U Fauzi, and F D E Latief

1Department of Physics, Institut Teknologi Bandung, Bandung, 40132, Indonesia

E-mail: leniaziyus@gmail.com

Abstract. Urinary stones are commonly differentiated into four types; calcium, struvite, cystine, and uric acid. While two of them, cysteine and struvite, could not be distinguished easily, in fact, they need a different kind of treatments. Significantly, the purpose of this study was to classify of urinary stones based on edge detection using a semi-automatic threshold. Five urinary stones were scanned using eight sources voltage. The source voltage was 65, 75, ..., 115 KV. The consistent parameters were set at; 0.2° rotation, 13.89 µm resolution, and 1 mm aluminum. The reconstructed images were quantified in CT Analyser 1.16.4.1. The region of interest (ROI) was a circle with a diameter of 275 pixels as well as the semi-automatic threshold were drawn on the reconstructed image. Based on the Hounsfield unit (HU) analysis, there were three groups of urinary stone on source voltage of 85 KV. The first group (struvite) has consisted of stone number 1 (461.42) and 3 (489.05). The second group (cystine) has consisted of stone number 2 (55.08) and 5 (-233.41). The third group was stone number 4 (634.18). The edge detection using semi-automatic threshold can classify five urinary stones into three types; struvite, cystine, and the other group.

1. Introduction

The stones are formed in the urinary system if concentrated minerals, such as calcium, oxalate, sodium, phosphorous and potassium [1] are crystallized into solid masses. The crystallization can be in the kidneys, ureters, and bladder. Based on the mineral composition, urinary stones are divided into 4 types; calcium oxalate, cystine, struvite and uric acid (UA) [2]. In particular, each of the four types of stones has to be treated by using different treatments.

The stones found in the urinary system can be destroyed through; drugs, extracorporeal shock-wave lithotripsy (ESWL), ureteroscopy, or percutaneous lithotripsy (PCNL). Drug consumption can alkalinize UA into soluble stones, then come out through urination. ESWL generates high energy shock waves to break struvite stones into a smaller piece, then removed from your body through urine. Meanwhile, cystine and calcium oxalate stones are removed from the urinary system through PCNL and surgery.

The X-rays from CT scans can distinguish urinary stones based on the value of the Hounsfield Unit (HU). Generally, several studies had been conducted to predict a urinary stone composition based on single energy [3,4]. The urinary stones can be determined based on the value of HU [5,6] and stones heterogeneity index [7]. Likewise, dual energy research has also been carried out to classify urinary stones by Wisenbaugh [8], Fitri [9], Ananthakrishnan [10].
In the previous research, however, it was stated that their overlapping HU values caused the difficulties of distinguishing cystine and struvite stones. Notably, it was believed that the essential factor in classifying urinary stones are determining the edge-detection. In this research, the value limit was considered as an information object to determine the mean HU value of the stone image. Therefore, the purpose of this study was to classify urinary stones based on edge detection through the semi-automatic threshold. Significantly, it was expected that cystine and struvite stones can be distinguished through proper threshold-based edge detection.

2. Materials and Method
In this study, each of five urinary stones with a diameter of 5-15 millimeters, was removed from the patient's body through surgery. As part of the preparation, the stone was arranged and placed in a transparent box as shown in Figure 1.

![Figure 1. Five samples of urinary stones](image)

The research methods were both qualitative and quantitative analysis. Qualitative analysis was done by observing the grayscale of the image. Then, the semi-automatic threshold distinguished the images of five urinary stones based on its appearance. Quantitative analysis was carried out by classifying the HU values of the samples’ scanning image (the five urinary stones) then compared them with the list HU values by NIST. Significantly, this research was conducted in several stages; scanning, reconstruction, analysis as follows.

2.1. Scanning
The urinary stone samples, arranged like Figure 1, were scanned by using micro CT SkyScan 1173. There were eight scanning parameters related to the source voltage and the variance of exposure time. Whereas, the geometry parameters were constant, which was set at; 0.2° rotation step, 13.89 μm resolution, and 1 mm aluminum filter. The scanning parameters results are shown in Table 1.

| Protocol | Source voltage (KV) | Source Current (μA) | Exposure (ms) |
|----------|---------------------|---------------------|---------------|
| 1        | 45                  | 177                 | 1500          |
| 2        | 55                  | 145                 | 1200          |
| 3        | 65                  | 123                 | 850           |
| 4        | 75                  | 106                 | 600           |
| 5        | 85                  | 94                  | 500           |
| 6        | 95                  | 60                  | 500           |
| 7        | 105                 | 50                  | 500           |
| 8        | 115                 | 50                  | 500           |
2.2. Reconstruction

The number of projection images produced by each scanning protocol was 1200. The images were reconstructed in 2-dimensional and 3-dimensional images by using Nreconstruction software. Reconstruction parameters - such as beam hardening (8), ring artifact correction (15), and smoothing (1) were constant for all eight scanning protocols. The parameters of reconstruction were 8% of beam hardening, 15 ring artifact correction, and 1 smoothing.

2.3. Analzyation

Reconstruction images were analyzed using CT software analyser. The Region of interest (ROI), a circle with a diameter of 275 pixels, was drawn on a 2-dimensional stone image. After the binary image stage, an edge detection analysis was performed on the image. Then, edge detection was done based on a semi-automatic threshold. However, the semi-automatic threshold calculated only based on the middle value on the histogram after the Otsu (automatic threshold) was applied. Otsu’s method is automatically identified based on its histogram. The method is based on statistical separability of the two classes (background pixels and foreground pixels) and automatically determines the optimal threshold without optimization procedure [11].

![Figure 2. Threshold values of the constructed images](image)

Based on the threshold, edge detection values on the histogram of the reconstruction image has shown in Figure 2 above. After Otsu’s method was applied, one of the stone images was at 157 grey level. The grayscale value of each pixel were >155, which considered as an object and <155 which considered as air. After counting the middle value of threshold by using Otsu method, it was found that the semi-automatic threshold was 44, meaning, if only the value of each pixel was > 44 will be counted or would be considered to be analysed in this study.

3. Results and Discussion

3.1. Qualitative Analysis

The qualitative analysis was done by observing the image of 5 urinary stones. Those images are showing in Figure 2 as following. As for qualitative analysis based on the figure above, each image was scanned using the variation of voltage parameters has shown grey and contrast gradations. Figure 3.a is brighter than 3.f, it was scanned by 65 KV source voltage which considered as more attenuated for five stones rather than scanned by using 115 KV source voltage. Meanwhile, stone number 2 and 5 remain darker even though it had been scanned by using various source voltage. These stones images were darker
because they do not absorb much X-ray. Based on the analysis, those five stone images were classified into three types. The first type consists of stones number 1 and 3, the second type consists of stones number 2 and 5, and the third type is number 4.

![Stone Images](image)

**Figure 3.** The construction images by using six source voltages

### 3.2. Quantitative Analysis
Quantitatively, the mean HU value of five stones for each source voltage is displayed in details as Figure 4.

![HU Values Graph](image)

**Figure 4.** The HU values of the variation of source voltage
Similarly, the result of quantitative analysis shown that the stones were divided into three groups. Figure 4 shows mean HU values for each stone as well as the NIS reference of HU value. At 85 KV, the mean HU value of stone number 4 is 634.18 which considered as a cystine type stone. Meanwhile, the mean HU value of stone number 1 is 461.42 and number 3 is 489.05 which considered as struvite stones. Unlikely, the other two types of stones cannot be determined.

Based on research conducted by Serrat (2017), the appearance of stones number 2 and 5 was identical to UA stones [12]. The mean HU value presented in figure 4 of stone number 2 was closed to HU value of the uric acid reference. It was found that based on the HU analysis, there were three groups of urinary stone on source voltage of 85 KV. The first group was consisted of stone number 1 (461.42) and 3 (489.05). The second group has consisted of stone number 2 (55.08) and 5 (-233.41). The third group has stone number 4 (634.18).

4. Conclusions
In summary, the edge detection by using semi-automatic threshold can classify five urinary stones into three types; struvite (stone number 1 and 3), cystine (stone number 4), and the other group (stone number 2 and 5). Urinary stone classification by using edge detection based on the semi-automatic threshold was more accurate if it was applied to heterogeneous urinary stones. Automatic-threshold (Otsu method) can be applied to homogeneous urinary stones because it acquired the middle value of the grayscale on each ROI. Following Liden’s research, automatically segmented 3D threshold method, where the threshold for each stone was defined as the half value between the peak stone attenuation (max-HU) and the background.

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