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# Ultrasound ComputerTomography Digital Image Processing for Concrete Hole Inspection

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**Abstract**
Digital image processing of ultrasound computer tomography for concrete hole inspection has been done. This system is ubiquitous for testing, inspection, and assessment of concrete quality. The investigated image was generated from ultrasound tomography imaging using the 1 MHz immersion transducer. Data dimension is from the tomography acquisition 100 projection x 63 ray sum. This data was then back-projected and a cross-section tomography image was obtained. The property of the hole being imaged was figured out by processing the image using Matlab. The first step of this research is loading and cropping ultrasound tomography image for calculation of the image's spatial resolution. The next step is tresholding to find out the shape of the hole being investigated. Calculation using image processing results in diameter, area, and position of the concrete hole. The results show that the investigated concrete hole diameter has a deviation of 0.06 cm or a relative error of 1.65% against standard measurements. The area of the hole has an average deviation of 0.61 $cm^2$ or a 5.2% relative error compared to theoretical calculations.

**Keywords:** inspection, ultrasound tomography, spatial resolution, image processing

## I. INTRODUCTION

Measurements of physical parameter of ultrasonic wave can be conducted without destroying the object and therefore beneficial for every day usage. The ASTM C957 elaborates material testing procedure using the ultrasonic pulse velocity method. This method only yields average measures of the objects investigated and is not capable of providing detailed conditions of the object along the trajectory of the ultrasonic wave [1]. Ultrasonic wave has some advantages compared to the other sources of radiation, i.e. it is portable, it poses less radiation, the price is reasonable, it helps to obtain numerous physical data, and it requires only a small power supply. Other than being applied for medical imaging, ultrasonic wave can also be used to investigate solid materials non-destructively [2].

In the non-destructive inspection, ultrasonic wave is generated by a piezoelectric transducer. This wave results in a compression that propagates along the material. This allows in-situ regular concrete investigation during a construction work [3,4]. The ultrasound test method determines a structural condition by an independent non-destructive phenomenon. It can investigate water-to-cement ratio in concrete, mortar age, state of concrete damage, cracks in concrete composites, compressive strength of high-volume mineral-admixture concrete, and cement adhesion, etc. [5,6,7,8].

Tomography is a method developed to image the cross-section of an object. It provides detailed explanation of the object being imaged. One of its advantages is the ability to compare microscopic physical characteristics such as radiation absorption profile of an object and a reference material [9]. Ultrasound tomography system has been used for non-destructive tests. In geophysics, this system has been used for imaging of dikes [10],i nvestigation of exploration drill joints, and study of ground layers [11]. In the chemical industry, ultrasound tomography system has been applied to detect gas and bubble types for uninterrupted filtration [12] that results in improved productivity, better homogeneity, minimum material intake, reduced energy consumption, lower environmental effect and less harm to people. Ultrasound tomography has been used as an online monitoring device for non-invasive and non-intrusive instrumentation and control [13,14,15].

Ultrasound computer tomography system has also been utilized to inspect concrete with a center frequency of 1 MHz. An image reconstruction based on summation of filtered back-projection is performed. The results show that all samples can be characterized and associated with their holes. The tomography image represents the value of time-of-flight and pulse velocity of concrete. These values have been compared with the values measured using the Sonic Viewer based on the ASTM C957 method and a linear correlation of 97.99% was obtained [16].

Further improvements in digital tomography imaging allow property analysis of samples. This automatic analysis system provides quick and precise assessment of minute particle deposit thickness on pipes [17]. Image processing enables scientists to investigate pore size distribution in order to understand the process of tissue generation and its related applications [18]. Digital image processing describes the geometrical model and configuration of concrete for elaboration of its inelastic nucleation, damage evolution, and also strength [19]. This research represents an analysis of computerized ultrasound tomography image processing method used to study the properties of concrete holes in terms of their diameter, area, and position.

## 2. ULTRASOUND COMPUTERTOMOGRAPHY IMAGING

The American Society for Testing and Material (ASTM) C 597-02 is a material testing standard used as reference in this research. It uses the longitudinal ultrasonic pulse velocity method to test concrete. The system is very simple in that a transmitter transducer is put on one side of the material tested, and a receive transducer is put on the other side of the material [1].

Once the ultrasonic transmitter and receiver are in place, the time of flight *($t_{of}$ )* of the wave can be figured out by calculating the time a pulse whichis induced by the transmitter to the time and it is recovered by the receiver [20]. The value of $t_{of}$ *to* some physical quantity, such as specific mass, modulus of elasticity, Young modulus, and Poisson ratio can be used to image the structure of solids [21]. Propagation of ultrasonic wave on a solid with length d is:

$$d = c.t_{of} \qquad (1)$$

Where $c$ is the wave velocity in the material, and $t_{of}$ is the time which takes the ultrasonic pulse to reach the receiver after travelling along the length $d$.

The $t_{of}$ from a measurement at a certain angle is called ray-sum, and a group of ray-sums at angle $\phi$ is called projection. The scanning process in an ultrasound tomography is depicted in Fig. 1. The emitted ultrasonic signal transmitted and received by the transducer is affected by factors such as the transducer's transfer function, water attenuation both in front of and behind the object, object's transmittance in water, and the pressure transfer function of the receiving transducer [22].

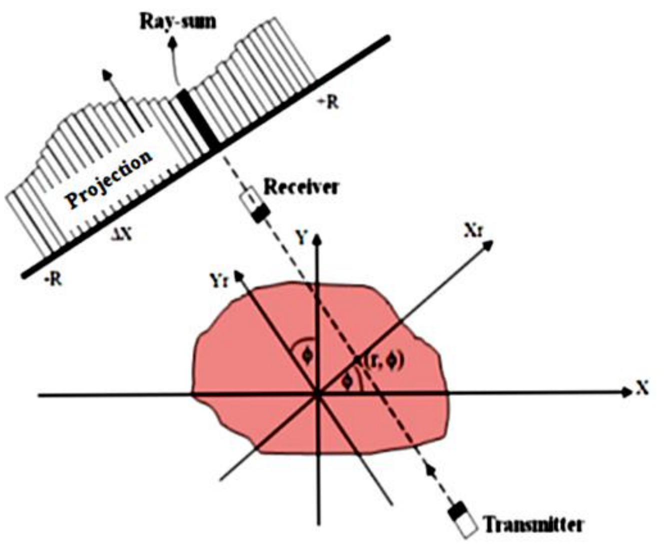



**Figure 1. Scanning process in ultrasound tomography**

One important physical parameter when an ultrasonic wave is radiated on an object is $t_{of}$, time of flight of ultrasonic wave on a surface of length $l$, and it is written as [16]:

$$t_{of} = \int_0^l \frac{1}{c(x)} .dx \qquad (2)$$

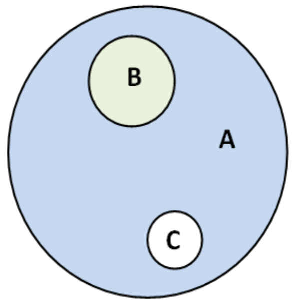
Where $c\ (x)$ is the ultrasonic wave velocity in an object of $dx$ thickness. By assuming that $A=1/c(x)$, the ray has an angle of $\phi$ against the y-axis. It is called a trajectory crossing point ($x_r$, $y_r$) in the rotational frame. The following equation includes both quantities:

$$t_{of}\ (\phi, x_r) = \int_{-\infty}^{\infty} A(x_r, y_r).dy_r \qquad (3)$$

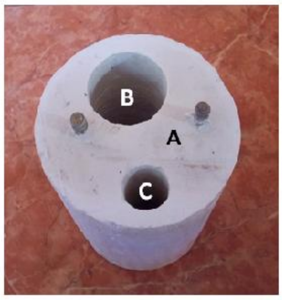
This is called the Radon transformation and is used to transform (*2-D)* images to (*1-D)*. The *1-D* line integral that crosses a point varies according to the cutting angle projection. Hence, Radon transforms a map domain function in the Cartesian coordinate *(x,y)* into the Radon coordinate ($x_r$,$\phi$). The description of these projection points in the Radon coordinate is known as Sinogram.

## 3. METHOD

The concrete sample tested in this research is cylindrical with a diameter of 12.43 cm. It is a mixture of cement and gypsum with 1:1 ratio. Here, it is referred as sample A. Two holes were then drilled, one was then filled with sand, and the other was left empty. These holes B and C are of 4.32 cm and 2.37 cm, respectively. Sample construction is depicted in Fig. 2a, where as the resulting sample is given in Fig. 2b.




**A**




**B**

**Figure 2. Sample construction cross-section (a), and the resulting sample (b)**

Data acquisition in the computed ultrasound tomography is conducted by shooting an ultrasonic pulse from the transmitter at 1 MHz frequency. The transducer is immersed in water and is put in opposition to the receiver. The ultrasound tomography used is time of flight *($t_{of}$)* mapping to obtain an acoustic impedance of the material. A microcontroller counts the $t_{of}$ and sends the result to a computer. This ultrasound tomography system uses data resolution (projection x ray sum) of 100 x 63. For each 63 ray-sum, a 1.8 degree angle rotation is made. The experimental scheme of this ultrasound tomography imaging is depicted in Fig. 3.

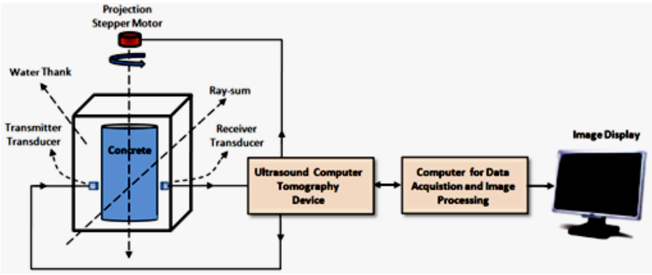



**Figure 3. Experimental scheme of the ultrasound computer tomography**

Data acquisition is automatically carried out using a personal computer. The interface system used is the serial UART microcontroller interface of 9600 BPS processing speed with RS-232 voltage level. The communication bandwidth is 8 bit, and therefore the multiplex data method is used to read the counts of time of flight. The data in the computer are displayed in the grid format. They are then stored in the text matrix format (*.txt) of 100 x 63. This data of time of flight known as sinogram will result in tomography images via the process of back projection algorithm. Back projection algorithm reconstructs tomography images from the sinogram space (Radon space) into two dimensional image space (Cartesian space) in the axial formation. This Summation Convolution Filtered Back Projection (SCFBP) method uses, as the name implies, two reconstruction processes, convolution and back projection.

In order to gain information on the properties of the concrete, a digital image processing is conducted on the tomography image. Software is devised using Matlab. It also comes with a Graphical User Interface (GUI) for real time monitoring on a computer screen. The GUI displays loaded images, processed images, and computational results. Coding for the GUI includes image loading, image cropping, gray level calculation, tresholding, and distance and area calculation.

## 4. RESULT AND DISCUSSION

An ultrasound tomography image was resulted from 6,300 data comprises of 100 projection x 63 ray-sum. Scanningisdone for each $1.8^{o}$ projection angle rotation and each ray-sum distance of 0.171 cm. Result of time of flight count is sent to a computer using a text format with ATT extension. Back projection then ensue and the resulting reconstructed ultrasound computer tomography image is shown in Fig. 4.

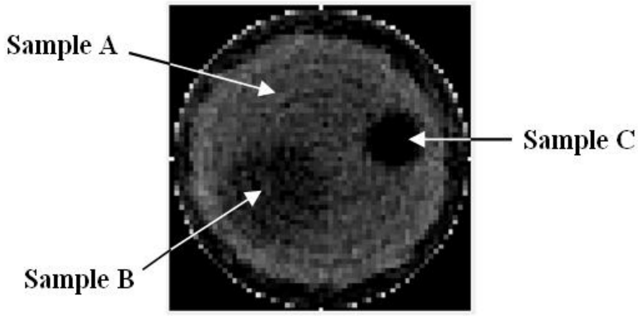



**Figure 4. Reconstructed ultrasound computer tomography image**

The reconstructed image is of8 bit resolution and reveals the two investigated holes. It is visually observable that both holes have different gray levels. Hole B, which is filled with sand, is brighter than Hole C, which is empty.The gray level value is then calculated by cropping the image of each hole as depicted in Fig. 5.

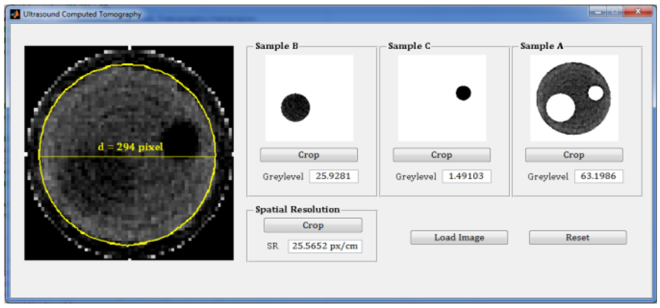



**Figure 5. Calculation of gray level for each hole**

The gray level of each object (hole) are following:sample B = 25.93, sample C =1.49, and sample A= 63.20. Sample A is calculated last as samples B and C has to be removed first.Values of this gray level are the foundation to determine the shape of the observed hole using the tresholding method. Tresholding values are set above and below an object's gray level value.The resulting tresholding image is shown in Fig. 7. The external dimension of sample A is used as reference for image size as its diameter is known. Spatial resolution (number of pixel per diameter) of image A is known to be 25.57 pixel/cm. From here, the diameters of the investigated holes can be calculated, as shown in Table 1.

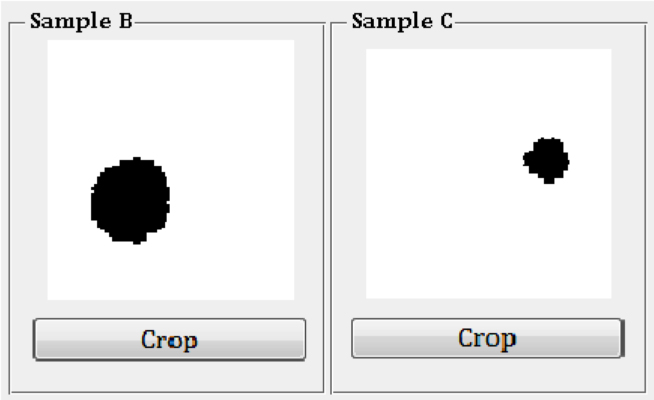



**Figure 7. Result of tresholding image**

Those results show that calculation of diameters using digital image processing results in values close to the measurements using standard tools with an average deviation of 0.06 cmor a relative error of 1.65 %. Meanwhile the calculation of area, a value close to its theoretical figure of 0.61 $cm^2$or a 5.2% relative error is obtained. This marginal error is mostly contributed by the hole containing material (sand). Experimentally, this is caused by the fact that the particular hole has inhomogeneous gray level that make it difficult to detect the edges of its image.

**Table 1. Calculation results forconcrete diameter and area**

| Sample | Diameter (cm) | | Diameter Deviation (cm) | Area ($cm^2$) | | Area deviation ($cm^2$) |
|---|---|---|---|---|---|---|
| | Imaging Method | Measurement reference | | Imaging Method | Calculation reference | |
| B | 4.39 | 4.32 | 0.07 | 15.71 | 14.64 | 1.07 |
| C | 2.41 | 2.37 | 0.04 | 4.27 | 4.41 | 0.14 |
| Average deviation | | | 0.06 | Average deviation | | 0.61 |

The other property of concrete holes that can be explained using image processing is their positions. These positions are calculated from the center of the image cross-section (axial image) of concrete, as depicted in Fig. 8. Calculation results using the centroid distance reveal distance of A-B = 2.47 cm, B-C = 5.91 cm, and C-A = 3.53 cm. These three positions can be used for further calculations as required.

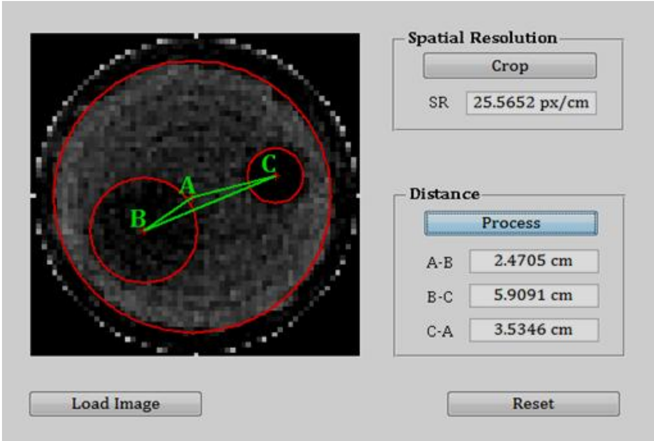



**Figure 8. Calculation of holes positions**

## 5. CONCLUSION

The ultrasound computer tomography digital image processing system built in this research proves to be able to image holes in an investigated concrete. It has been used in analyzing hole samples that either contained material and/or was empty based on their gray level.The tresholding method is used to analyze hole images and compare them to background images to determine the shape and diameter of those holes. These values could then be used to figure out the area of the holes and the distance or each hole from the center of the concrete cylinder. Results of calculations using the system here are then compared to measurements using standard tools and also theoretical values. Results indicate that hole diameters have an average deviation of 0.06 cm or a 1.65% relative error compared to standard measurements, whereas hole areas have an average deviation of 0.61 $cm^2$ or a relative error of 5.2% compared to theoretical values. This marginal error is mostly contributed by the hole containing material (sand). Experimentally, this is caused by the fact that the particular hole has inhomogeneous gray level that makeit difficult to detect the edges of its image.

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