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Image Processing for Corrosion Quantification in Concrete Slabs using GPR data

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Abstract. This study aims to quantify the corrosion of steel reinforcing bar (rebar) in concrete structures using ground penetrating radar (GPR) and image processing techniques. A method to accelerate corrosion of steel rebars in concrete slab to different level of corrosion is applied. The power supply and the electrolyte are used to induce significant corrosion within a short period of time. The 2 GHz GPR is used to assess the corrosion in the reinforced concrete slab after 28 days of standard moist preservation. GPR method has been found to be useful for quantifying steel corrosion on existing concrete slab. The image processing techniques were used to process the GPR data. The results of the analysis of the GPR data shows that corrosion of the rebars could be detected. The subsequent image processing technique exhibits that corrosion of the rebars could be appropriate quantified.

1. Introduction

Corrosion of steel reinforcing bar (rebar) in concrete structure causes sub-surface cracks was a major cause of structural degradation and delamination [1, 2]. There were many factors that induce the steel rebar corrosion, i.e. moisture and chloride contents of concrete and the change of the water and chloride content along with the delamination around steel rebar [3, 4]. Ground penetrating radar (GPR) has become a technique for corrosion detection of concrete structure over the past few years [4-10]. Previous studies have shown and developed system for quantifying of the GPR images. However, the interpretation of the GPR images is very difficult since the heterogeneous concrete and the capability of GPR system in highlighting discontinuities within the concrete structure [11-16]. Image, signal processing, pattern recognition and neural network techniques have been used for and analyzing and interpreting the GPR data [17-20], however, the success has so far been limited to corrosion quantification cases [12, 21]. Hence, this study is motivated to represent the image processing techniques for quantifying steel corrosion using the GPR data.

2. Materials and Method

2.1. Specimen Preparation

This concrete specimen was the different specimen with previous study of author (Zaki et al. 2018). The concrete specimen of this study is pre-corrosion concrete slab. For pre-corrosion concrete slab, the steel

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rebars were first subjected to corrosion prior to concrete casting using the induced current technique (galvanostatic method). The induced current technique in accordance to ASTM G1-03 [22]. The accelerating corrosion process was continued until the steel rebars achieved the required level of corrosion or mass loss. The mass loss was determined using Faraday's law [23]. Therefore, after the steel corrosion process, the steel rebars were then cleaned to remove corrosion product (*rust*) in accordance to ASTM G1-03 [22] and weighed to determine the final mass of the steel rebars. Corrosion levels of the steel rebars based on the percentage of mass loss (the difference between initial and final mass) [24]. After obtaining the required corrosion level of steel rebars, the rebars were installed in formwork for casting of the concrete specimen. The grade 30 concrete specimen with dimensions 1000 x 500 x 200 mm^3 was prepared. The dimensions and concrete mixture of the concrete specimen are same with the previous study [7].

2.2. GPR Data Acquisitions
The 2 GHz GPR manufactured by IDS (Ingegneria Dei Sistemi S.p.A) Italy, was used in this study. The concrete specimen was scanned using the GPR equipment. Scanned GPR data are showed in a-scan, b-scan, c-scan, and 3-D images by GREED software. The 3-D images which are processed using image processing techniques. The Figure 1 shows the GPR equipment.

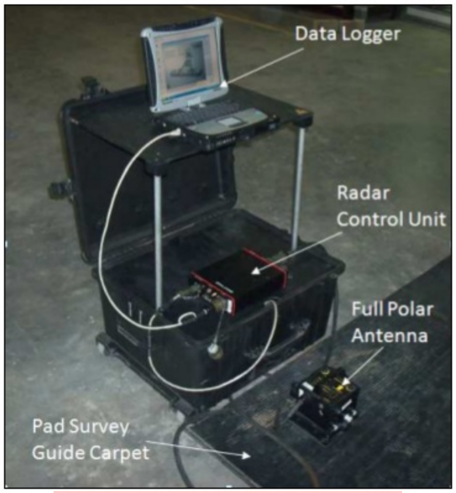

Figure 1. GPR ALADDIN SK2 kit

2.3. Image Processing Technique
The 3-D image is cropped to size 100 x 275 pixels for each condition. Two image processing techniques were applied, i.e. *k*-means clustering and binary image converting. Both of techniques were proposed using Matlab software. The image with size 100 x 275 pixels was proposed for the clustering. The clustering image was extracted to be a binary image. The features of binary image, i.e. rebars size and

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average diameter. The black and white segmentation of the binary image was chosen for quantifying the steel rebars corrosion of the concrete slab. The image processing technique were shown in Figure 2.

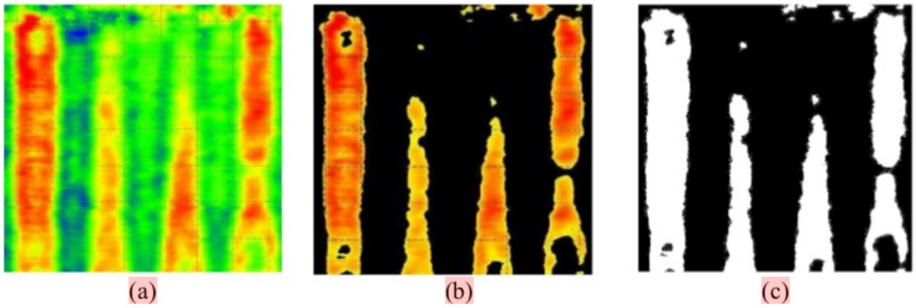

Figure 2. (a) GPR image, (b) *K*-means clustering image, and (c) Binary image (Zaki and Kabir)

3. Results and Discussion

Figure 3 shows the steel rebars with different corrosion level after accelerating corrosion process. The rebars a, b, c, and d are the non-corroded rebar, low corrosion rebar, middle corrosion rebar, and high corrosion rebar, respectively.

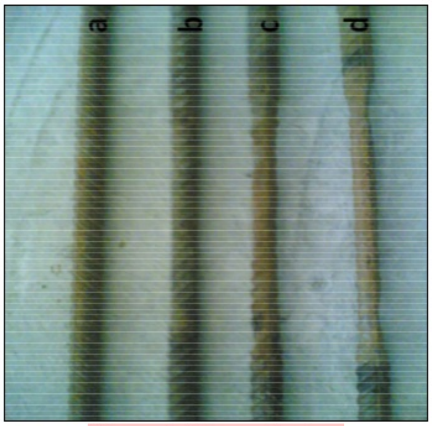

Figure 3. The steel rebars

Figure 4 shows the 3-D GPR image of the concrete specimen. From the observations was shown in the figure, the 3-D image could be utilized for analyzing the steel rebars corrosion of the pre-corrosion concrete specimen. The 3-D image agree with the actual rebar conditions of as showed in Figure 3.

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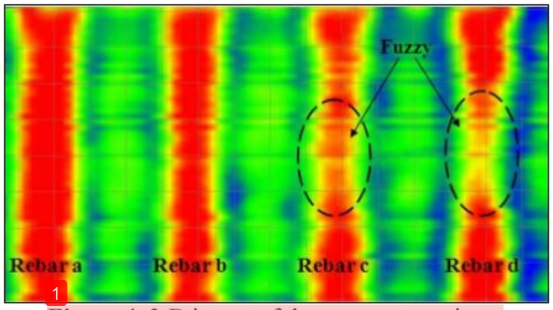

Figure 4. 3-D image of the concrete specimen

The Figure 5 (a)-(d) is the clustered images of GPR data. The clustered images were chosen for the *k*-means clustering algorithm and converted to binary images.

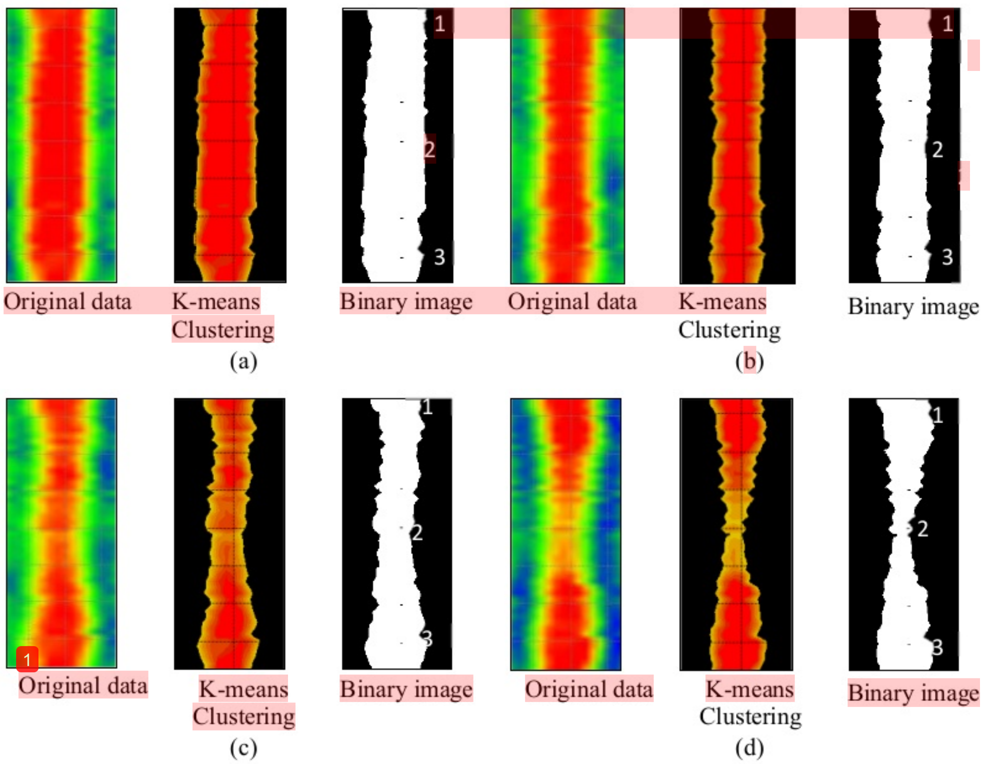

Figure 5. *K*-means clustering, and binary images of the concrete slab: (a) rebar a, (b) rebar b, (c) rebar c and (d) rebar d

The conversion of the clustered images to the binary images was required in order to analyze the rebar using the image easily. The two features (i.e. area of rebar and diameter of rebar) can be calculated based on the binary image using features extraction. The results of the calculation of the area and the diameter of rebar are tabulated in Table 1 and Figure 6. The binary images were labelled at three locations 1 (top), 2 (middle) and 3 (bottom) to show the variation of diameter in term of pixel lines. The locations of

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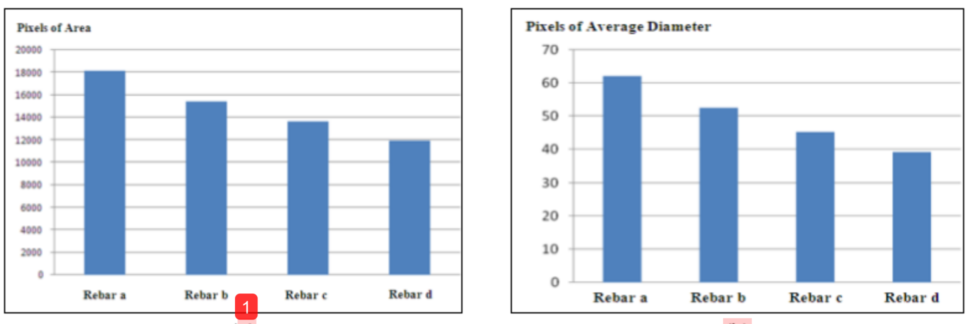
binary image represent the conditions of the steel rebar. The pixels area and the average pixels diameter decrease in terms of increase of corrosion level of concrete slab.

Table 1. Binary image features of the concrete slab

	Rebar a	**Rebar b**	**Rebar c**	**Rebar d**
Pixels area	18158	15447	13635	11912
Label 1 (diameter)	63	58	57	56
Label 2 (diameter)	63	47	36	16
Label 3 (diameter)	61	55	64	61
Maximum pixels of diameter	69	59	68	61
Minimum pixels of diameter	52	44	32	16
Average pixels diameter	62.14	52.49	45.37	39.21



(a) (b)

Figure 6. (a) bar chart of pixels of area and (b) bar chart of pixels of average diameter

4. Conclusion

Several results can be obtained by using GPR technique for detection of the rebars in the concrete slab, that are a-scan, b-scan, c-scan and 3-D image. The 3-D GPR data image was chosen as data image for image processing techniques. The results of assessment show that *k*-means clustering and binary image of image processing techniques produced good assessment. The pixels of area and average of diameter decrease due to the increase of degree of corrosion.

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