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INVESTIGATING DIFFERENT IMAGE PROCESSING TECHNIQUES FOR BETTER INTERPRETATION OF GPR IMAGES

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Abstract: Interpretation of Ground Penetrating Radar (GPR) image is an essential process in bridge deck condition assessment. For this purpose, raw GPR images should be clear and more comprehensible. A GPR image usually has some blurriness and noise due to the lack of illumination and environmental conditions. Image processing techniques offer some preprocessing steps for removing noise and for quality enhancement of images. Image preprocessing has various filtration techniques, such as Gaussian filtering method, Median filtering method, etc. A GPR image in bridge deck condition assessment shows the bridge deck surface, top and bottom rebar, and bottom of the bridge slab. Usually, corrosion happens around the rebar mat and it is shown as a signal attenuation in the GPR image. However, the main issue is that the bottom rebar in GPR image is not entirely visible. To address this issue, this paper presents several image preprocessing techniques to improve and prepare GPR images for easy interpretation in bridge deck condition assessment.

Keywords: GPR image; Bridge condition assessment; Image processing techniques;

1 Introduction

1.1 GPR Principle

GPR is one of the most common and powerful devices used in Non-Destructive (NDE) test for bridge condition assessment. For bridge inspection, a high range of frequency (more than 1 GHz) is required (Shakibabarough, et al., 2017). A GPR device is composed of an encoder, electronic unit, control unit, antenna (ranging from 50 MHZ to approximately 1.5GHZ), and a monitor. The encoder determines the distance the GPR must move and requests a pulsing radar signal at that interval. In response to the request, the control unit produces and sends a digital radar signal to the electronic unit, which converts it to an analog signal and directs it to the antenna to pulse the specified area. The antenna then sends electromagnetic (EM) waves to the defined surface. When they encounter an interface between two layers, some of EM waves penetrate, and the rest are reflected back to the control unit, which records its amplitude after calculating the signal's two-way travel time (Shuai et al., 2016). The reflected signal waves from the rebar mat is displayed as a series of hyperbolas and the top of the hyperbolas show the rebar's position (Shakibabarough, et al., 2017).

The GPR image, shown in Figure 1, shows the deck surface, top rebar, bottom rebar, and slab bottom as different layers. The colored dots, as shown in Figure 1, (blue – top of the slab, red – top reinforcing bar layer, and green – bottom reinforcing bar layer) indicate where amplitude measurements were taken.

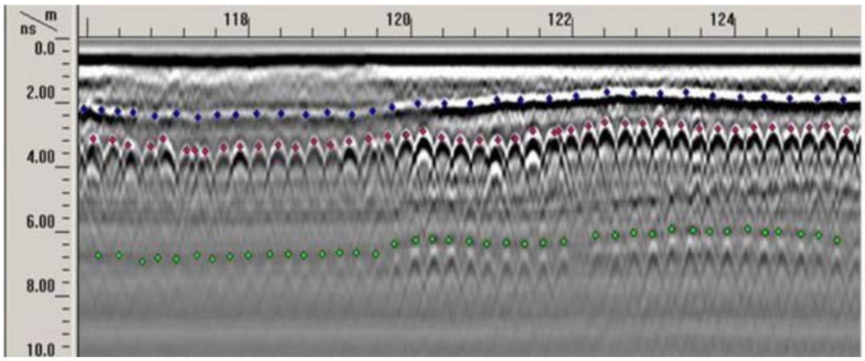


Figure 1: The GPR profile of a bridge deck in Queens, NY (Tarussov et al., 2013)

A GPR device usually collects data in parallel directions at a distance of 2 feet, hence if the upper bar is transverse, the device collects 14 files for a parallel line of traffic, and 4 feet from the edge is the onset direction because of the traveling line. The device collects 24 scans/feet or one scan/0.5 inch to provide an accurate image of the rebar location. The data collection usually takes 30 minutes (Shakibabarough, et al., 2017). When the data is collected, the raw GPR images have low quality, which needs to be pre-processed using some techniques such as filtration and migration techniques. Each raw GPR image has some noise resulting from environmental complexity and interference from other nearby electromagnetic activity, such as that from cell towers (Shakibabarough, et al., 2017). Sometimes, the image obtained from the sensor or satellite has low contrast and brightness due to the limitation of illumination and environmental conditions. Therefore, image enhancement techniques, such as contrast stretching and histogram equalization and noise filtering, should be used in the feature extraction process.

The objective of this study is to investigate several image preprocessing techniques in improving and preparing the GPR image to provide an output for easy interpretation in bridge deck condition assessment process.

1.2 Image Processing Principle

"Noise" indicates the existence of any undesirable or unwanted objects or information in an image, that directly affects artifacts, unrealistic edges, invisible lines, and corners, blurs objects, and disturbs background scenes (Boyat and Kumar Joshi, 2015). Image Processing is a technique used to acheive better quality of raw images received from cameras/sensors placed on satellites, space probes, and aircrafts or pictures taken in ordinary daily life for various applications (Lee et al., 2008).

Recently some technologies have been developed for visual inspection to increase the reliability of inspection, such as digital image processing (Abudayyeh et al., 2004). The term digital image processing refers to the processing of a two-dimensional picture by a digital computer. A digital image can be used for offsite inspection, rather than onsite inspection, with the same level of accuracy (Rhazi et al., 2003). Several techniques have been developed in Image Processing within the last four to five decades. Most of the methods are designed for enhancing images obtained from unmanned spacecraft, space probes, and military reconnaissance flights. Image Processing systems are becoming popular due to the easy availability of powerful personal computers, large size memory devices, graphics software, etc. Image processing has three main steps: image acquisition, image analysis and manipulation, and communication and display. In the image acquisition stage, an object in the image is recognized and converted to digitized format using equipment, like a digital camera. In the image analysis step, the quality of the image is improved, and some additional objects are removed from the image.

The goals of image processing could be categorized as: Visualization: to detect invisible objects, Retrieval: to detect the image of interest, Sharpening and Restoration: to create a high-quality image, Recognition: to classify a correct object within the image, Measurement of the pattern: to determine the object of interest within the image (Kaur and Kaur, 2015). Image preprocessing is an important phase of image processing process which is applied for removing noise and increasing GPR image quality. There are some preprocessing techniques like filtering techniques for eliminating noise in images, such as the Gaussian filter and median filter (Shakibabarough, et al., 2017), and image enhancement technique which are addressed in the following sections.

1.2.1 Median Filter

Median filtering is a nonlinear method used for removing noise from images. This filtering method is very efficient for removing noise, while preserving edges. It works by moving through each pixel of the image. The median filter replaces the pixel at the center of the filter with a median value of the pixel. This technique does not blur the image, but it can round the corners. Hsieh et al. reported that median filter is a very efficient and robust filter for removing salt and pepper noise from the image (Hsieh et al., 2013). The basic concept of the median filter, shown in Figure 2, is to consider the middle gray level value within a square window of size P*P (pixel). The value of the central pixel in the square window changes with the intermediate gray level value. Figure 3 shows a sample of a GPR image filtered and smoothed by the Median filtering method.

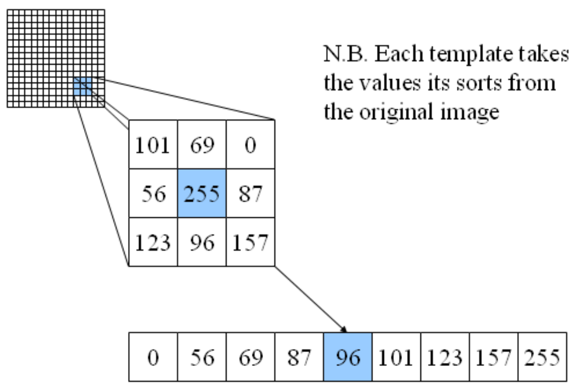


Figure 2: An example of median filter distribution

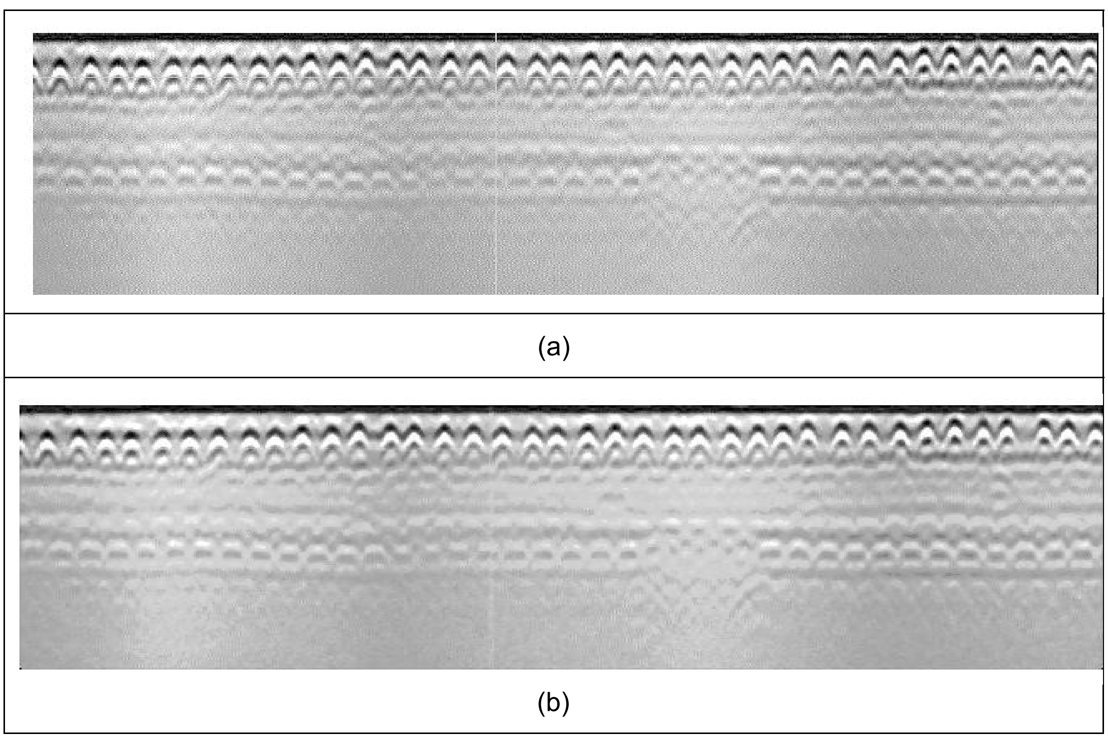


Figure 3: Sample of raw GPR image (a) and image filtered by the Median filtering method (b)

1.2.2 Gaussian Filtering Method

The Gaussian smoothing method is mainly used for smoothing bluer images or removing noise. Mathematically, Gaussian filtering modifies the input signal by convolution with a Gaussian function; this transformation is also known as Weierstrass transform. The one-dimensional Gaussian filter has impulse response and the frequency response given by the Fourier transform with the typical frequency in two dimensions, which is the product of two such Gaussians, one per direction. Where x is the interval from the origin in the horizontal axis, y is also the interval from the source in the vertical axis, and σ is the standard deviation of the Gaussian distribution.

Equation 1 and 2 show Gaussian smoothing in 1D and 2D respectively (Mark and Alberto, 2008; Shapiro and Stockman, 2001). Figure 4 and 5 show the Gaussian distribution in 1D and 2D respectively.

[1] $$G(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}}$$

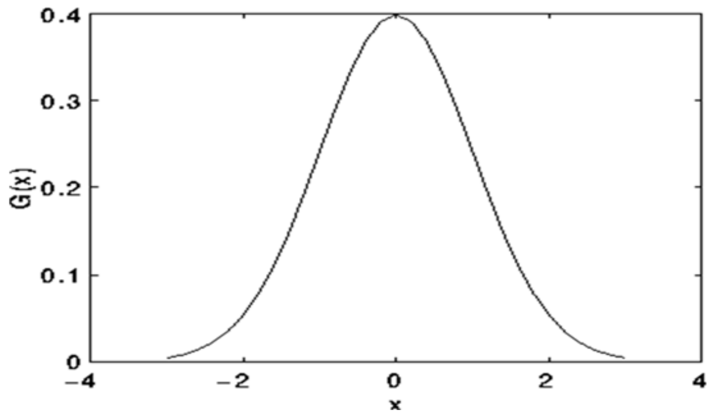


Figure 4: Gaussian distribution in 1D (Fisher et al., 2003)

[2] $$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

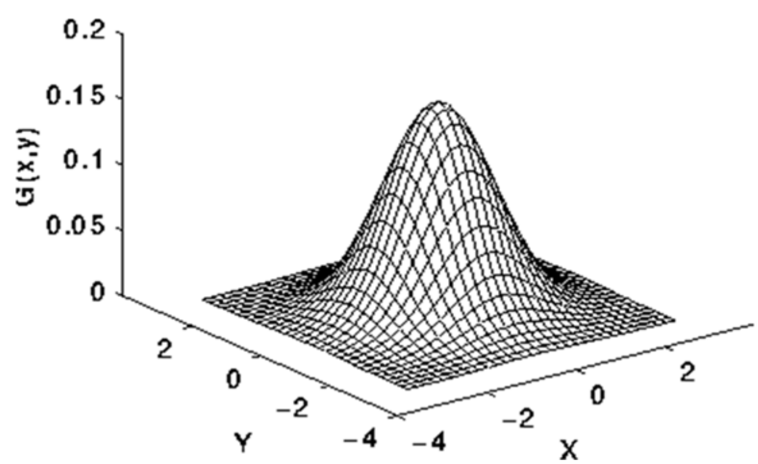


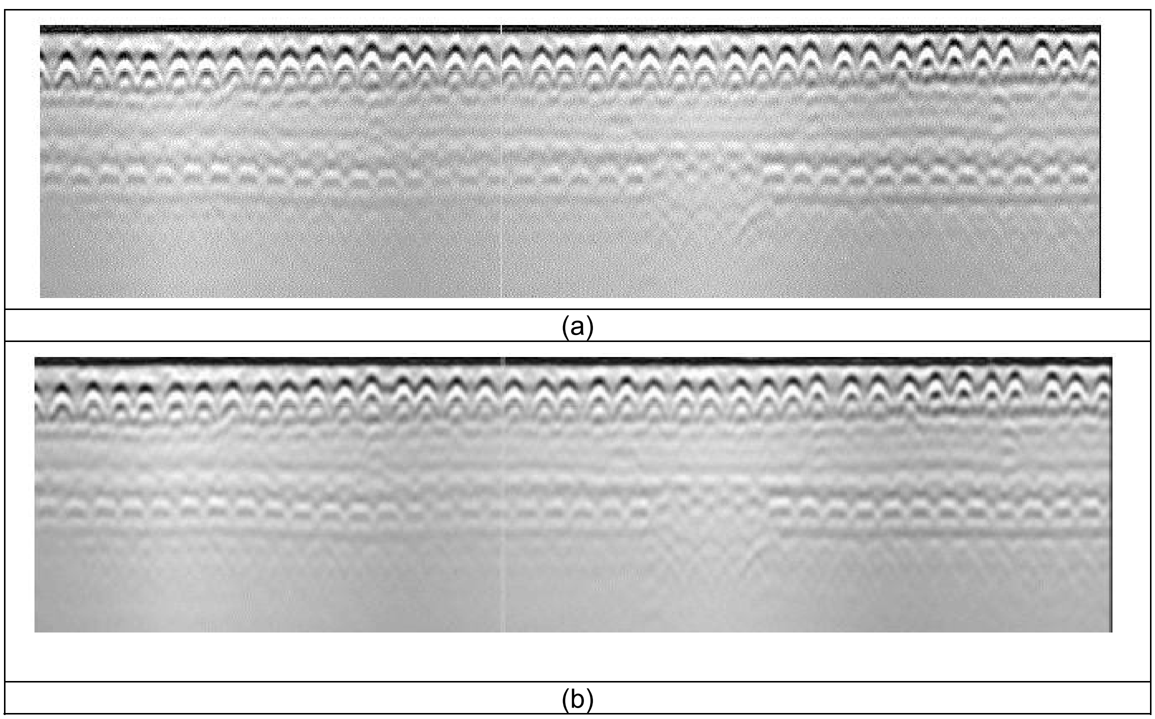
Figure 5: Gaussian distribution in 2D (Fisher et al., 2003)

Gaussian filtering operates as a point spread function using convolution. The image is stored as discrete pixels, and then these pixels are entirely integrated with Gaussian value. Figure 6 represents a discrete approximation of Gaussian filtering. The Gaussian filter is designated as non-uniform low pass filtering. Figure 7 shows a sample of a GPR image filtered and smoothed by the Gaussian filtering method.

Each scan is shown as an image after a preprocessing technique, such as Gaussian filtering, removed any noise in the image. Each digital image usually has several types of noise due to the environment complications and conditions, such as lower illumination, high temperature, electronic transmission circuit noise, and so on. Image smoothing and removing noise are used for minimizing the effect of noise and developing the quality of the image. In GPR profile, as can be seen in the above figures, the top rebar is clear, but the bottom rebar is not completely clear due to the depth and lower signal reflection. Therefore, image enhancement should be considered here for better representation of the bottom layers.

$$\frac{1}{273}\begin{bmatrix} 1 & 4 & 7 & 4 & 1 \\ 4 & 16 & 26 & 16 & 4 \\ 7 & 26 & 41 & 26 & 7 \\ 4 & 16 & 26 & 16 & 4 \\ 1 & 4 & 7 & 4 & 1 \end{bmatrix}$$

Figure 6: Discrete approximation of Gaussian filtering



(a)

(b)

Figure 7: A sample of GPR image (a) and image filtered by the Gaussian filtering method (b)

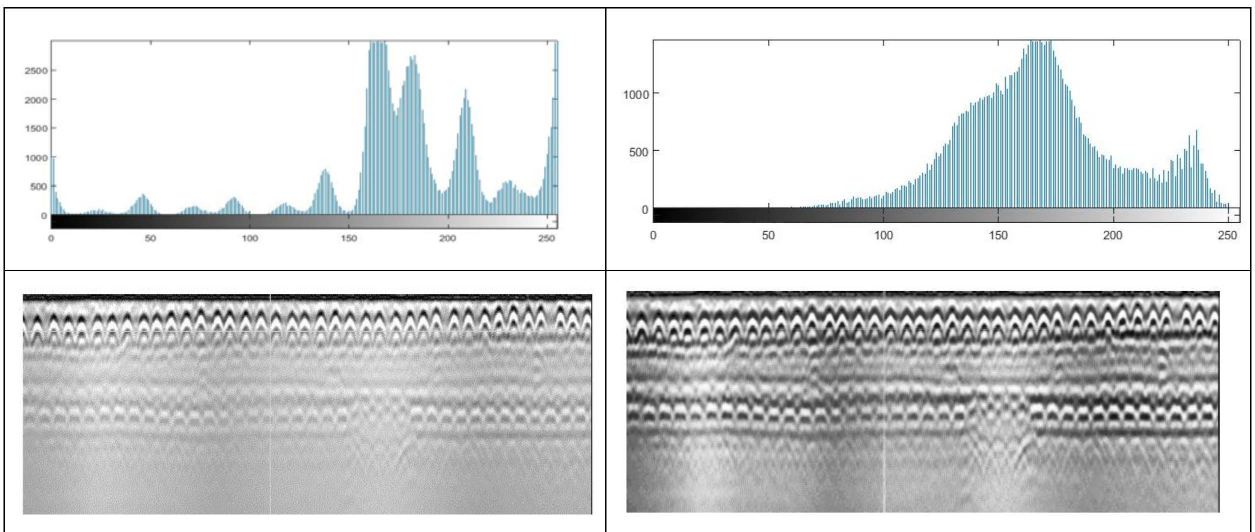
By comparing GPR images filtered by Gaussian and Median filtering methods (Figures 3 and 7), it can be concluded that the image filtered by the Gaussian filter is better for enhancement because of less white pixels created in the image.

1.3 Image Enhancement

Image enhancement is the subdivision technique of image processing to enhance specific features of the image. The primary target of image enhancement is achieving a high quality of the image, a better understanding of the image, and also a straightforward visual interpretation. In other words, the outcome of image enhancement is more suitable than the raw image. There are many image enhancement techniques, therefore choosing an appropriate image enhancement method is significant, depending on the feature of the image that needs to be enhanced. Images captured by devices like a camera or any other device may become dark for various reasons. Hence some image enhancement techniques could develop images by increasing their contrast or intensity. In a grayscale image, also known as a black and white image, each pixel has only one value, which is the intensity of the pixel. The value may range from 0 to 225. A grayscale or grayscale digital image is an image in which the value of each pixel is a single sample, which carries only intensity information. Grayscale is compounded exclusively of shades of gray, varying from black at the weakest intensity to white at the strongest.

1.3.1 Histogram Equalization

Histogram equalization is a technique for adjusting the image intensities to enhance image contrast. A histogram of an image can be plotting pixel intensities versus frequency of the pixel intensities or probabilities of the pixel intensities. One way of producing a histogram is to plot pixel intensities versus pixel frequencies. Figure 8 shows an original image and a histogram versus a histogram and an image after equalization.



a) Original histogram and GPR image | b) Histogram and GPR image after equalization

Figure 8: GPR image and equalized histogram image

2 Model Implementation

In this study, we used some real GPR images to apply pre-processing phase, described in previous section, for removing noise and doing image smoothing to make better visualization and interpretation. The GPR images were provided by Ingegneria Dei Sis-temi (IDS) Geo Radar company. The GPR device used by the company uses a 1.5 GHz antenna, which was used for scanning a concrete bridge deck located in New

Jersey, USA. Two samples of original GPR images of a real bridge deck in New Jersey State, provided by IDS Geo Radar company, were pre-processed, in this study, using techniques described in the previous section. Figures 3, 7, 8 and 9 show the application of different operators on the sample image. Each Digital image usually has several types of noise due to the environment complication and condition such as lower illumination, high temperature, and electronic transmission circuit noise, and so on. In other words, noise is an outcome of errors in image acquisition process that does not reflect true intensity of that pixel value. Image smoothing and de-noising are used for minimizing the effect of noise and enhancing the quality of the image. In GPR profile, as can be seen in Figure 8-a, the top rebar is clear, but the bottom rebar is not completely clear because of the signal attenuation due to the depth and lower signal reflection. After removing noise and applying image enhancement, the image is ready for interpretation. Interpretation usually is implemented by an analyst who has experience adequately interpreting GPR images. Any signal attenuation on the GPR image or significant variations in signal amplitude, show corrosion on rebar in reinforced concrete bridge deck assessment. As mentioned earlier, bottom rebar is not seen visibly on the GPR image due to a high depth from the deck surface, but this problem can be solved with image enhancement technique. Figure 9 shows the process of converting the raw GPR image to a clear image automatically by using an image processing technique. Enhancement of all images of bridge decks, which have been scanned by GPR, takes a significant amount of time, but by using image processing technique, enhancement of all images can be automatically conducted.

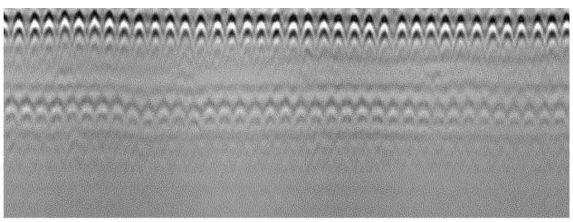
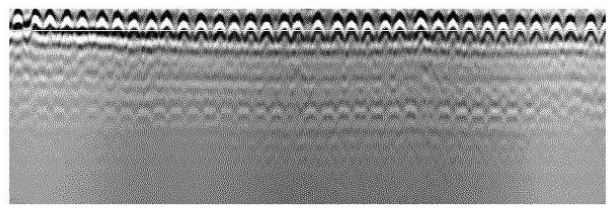
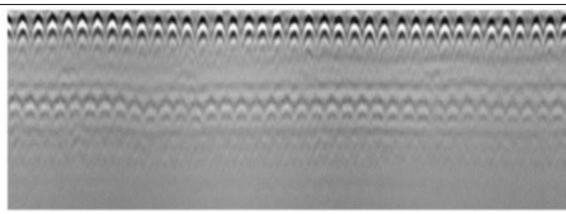
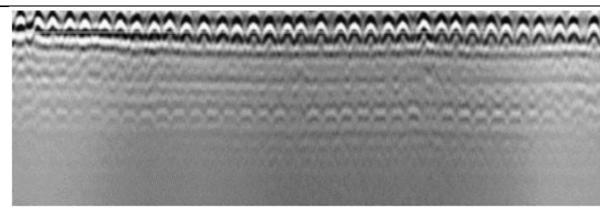
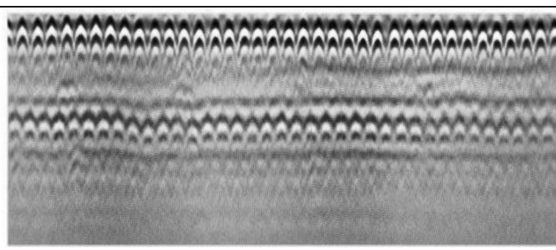
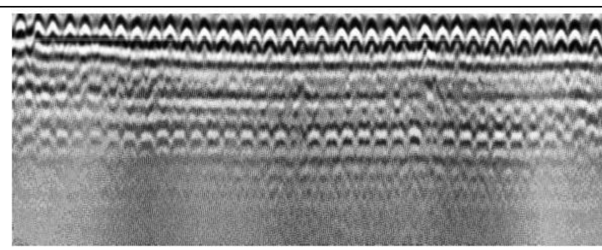
	
A1) Raw GPR image	A2) Raw GPR image
	
B1) GPR image after noise filteration	B2) GPR image after noise filteration
	
C1) Enhanced GPR image	C2) Enhanced GPR image

Figure 9: The process of GPR image preparation

3 Conclusions

GPR is a useful tool among all NDE methods for bridge deck condition assessment. Raw GPR images have some noise and can have low quality due to environmental conditions and low illumination. The top rebar on a GPR image is seen easily, while the bottom rebar cannot be easily identified. The histogram equalization technique has been used for improving the quality of the bottom layer and to make the bottom rebars more visible. Preparation of the GPR image is labor-intensive and time-consuming. Therefore, automating the preparation process for all GPR images of reinforced concrete bridge decks is necessary for increasing the quality efficiency and decreasing preparation time. In that case, automated preparation of GPR images can be very beneficial. The mentioned image processing techniques can be used to prepare a high volume of GPR images from the reinforced concrete bridge deck to make them ready for easy and rapid interpretation.

After applying the pre-processing phase on two samples of original GPR images of a real bridge deck provided by IDS Geo Radar company, as shown in Figure 9, the overall quality of GPR images was improved, and the bottom rebars became more visible which can help engineers to assess the condition of bridge simpler and more effective. Finally, it was observed that the result is completely effective for easy interpretation through visualization technique.

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