Automated Detection of Areas of Deterioration in GPR Images for Bridge Condition Assessment

Azin Shakibabarough[1], Ashutosh Bagchi[2], and Tarek Zayad[3]

[1, 2, 3] Department of Building, Civil and Environmental Engineering, Montreal, Canada

ABSTRACT: The bridge deck is considered one of the main components in a bridge management system; its service life is shorter than that of the other elements because it protects the bridge's substructure. Non-destructive Evaluation technique have been used for bridge condition assessment. Among them, Ground Penetrating Radar (GPR) is commonly used in bridge deck condition assessment. For a given bridge project, the final interpretation of GPR image leads to the assessment of the bridge operational condition, so it should be very accurate. Using a visualization method to interpret GPR data is common and provides precise results, but this process is long and time-consuming, so developing an automation process could solve this problem. Although some publications do focus on automatic detection of deterioration, this paper proposes a novel method for detecting areas of deterioration in rebar mat signatures with GPR imaging using MATLAB image processing tools. The proposed algorithm has been tested and validated on many real GPR images.

Keywords: bridge deck, Ground Penetrating Radar (GPR), deterioration area, image processing, condition assessment.

1 INTORDUCTION

Recently, bridge management systems have been widely adopted because of tragic failures leading to human and financial losses. In 2009, the Federal Highway Administration reported that 11.5% of U.S. highway bridges have structural deficiencies or obsolete functionality (FHWA, 2009). Over 14% of bridge decks need rapid rehabilitation, and over 46% of bridge decks need some rehabilitation within the next 10 years (Bisby, 2006). The main components of bridges include the bridge deck, superstructure, and substructure, but decks have a shorter service life than other parts because the deck surface protects both the substructure and superstructure against environmental contaminants; thus, evaluating the bridge deck is an inevitable part of a bridge management system (Vaghefi et al, 2012).

Using subsurface sensing and imaging (SSI) techniques to assess bridge conditions for appropriate maintenance action could be critical (Shin et al, 2003) . Ground-penetrating radar (GPR) is an electromagnetic evaluation technique used for concrete evaluation, geology, archeology, and utility detection. However, GPR's most important use is evaluating reinforced concrete decks and other concrete structures (Romero, 2003). Among SSI techniques, GPR is one of the best methods for evaluating concrete bridge decks; Cardimona et al. recommended GPR as an appropriate tool for detecting defects in steel rebar within concrete decks(Cardimona et al, 2001)

GPR manufacturers provide antennae ranging from 50 MHz to approximately 1.5 GHz. For bridge inspection, the GPR should be higher than 1 GHz. The optimal setup for using GPR to assess the condition of a concrete structure includes high frequency (1.5 GHz) ground-coupled antennas that provide great identification and resolution of steel reinforcement, which results in a better map of the deterioration.

Currently, precise assessment of concrete bridge decks and identification of delamination are the main concern of bridge management systems that could lead to economic savings (Wang et al, 2012). GPR has several advantages over conventional methods such as chain dragging and hammer sounding because it acquires data at a high rate and minimize traffic disruption (Hugenschmidt, 2002). GPR comprises an encoder, electronic unit, control unit, antenna, and monitor. The encoder determines the distance the GPR must move and requests a pulsing radar signal at that distance. 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 specified surface. When they encounter an interface between two layers, some of the EM waves penetrate and the rest are reflected back to the control unit, which, after calculating the signal's two-way travel time, records its amplitude (Shuai et al, 2016).

The drawbacks of final GPR interpretation, or post-processing, include relying on the operator's expertise and on scan-by-scan processing. Through automation, image processing technique could improve bridge deck condition assessment. In GPR images, signal attenuation indicates areas of deterioration that generally occur around the concrete rebar mat. Corroded areas in rebar have a lower dielectric constant than sound rebar, which leads to both attenuation and a weaker reflection signal. The GPR image shown in Figure 1 shows the deck surface, top rebar, bottom rebar, and slab bottom as different layers. The reflected signal waves from the rebar mat display as a series of hyperbolas, and top of hyperbolas denote the rebar's exact position.

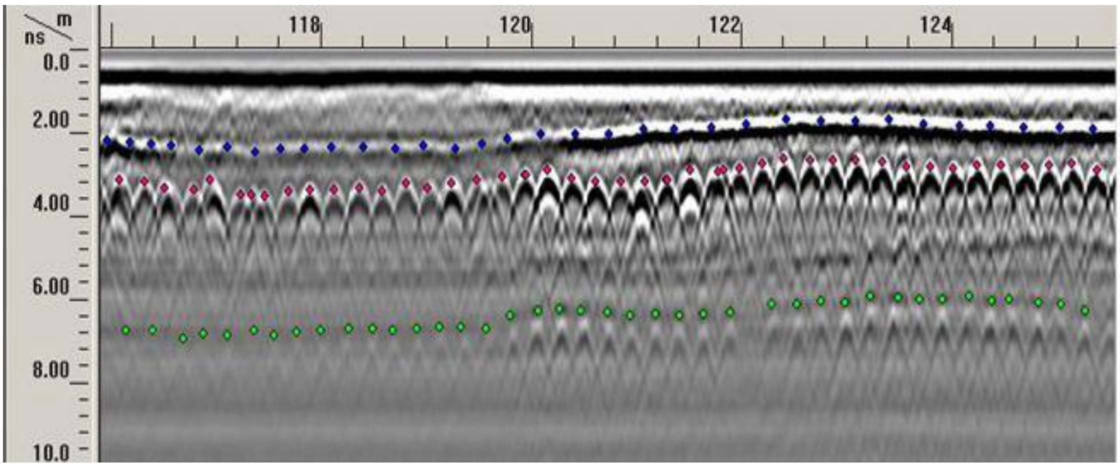


Fig. 1: GPR profile of a bridge deck in Queens, NY. The colored dots (blue – top of the slab, red – top reinforcing bar layer, and green – bottom reinforcing bar layer) indicate where amplitude measurements were taken (Tarussov et al, 2013)

GPR image interpretation is very a significant task, so precise interpretation of GPR images can lead to a precise assessment of a bridge's condition. Numerical analysis and visualization techniques are usually used to perform GPR image interpretation. Numerical analysis of a GPR image involves measuring the radar's amplitude response and mapping those values. Visualizing GPR images involves marking any attenuation part that shows deterioration. Tarussov et al. explained that visualization is more accurate than numerical analysis for GPR image interpretation because, unlike numerical analysis, visual analysis can easily eliminate small amplitude variations that appear as corroded areas(Tarussov et al, 2013).

Currently, detecting deterioration in bridge decks is important for bridge management, so analysts mark those areas in GPR visualization; however, this process, which requires scan-by-scan processing, is very time consuming and labor intensive. Chen et al (2002) proposed a neuro-fuzzy recognition approach for detecting bridge coating defects. Nguyen et al. (2009) applied image-processing techniques for pavement crack detection. Lee et al (2008) introduced an automatic crack detection algorithm based on intensity differences between the crack and its background. Recently, some technologies such as digital image processing, have increased the reliability of visual inspection (Abudayyeh et al, 2007). Digital imaging could be useful for both off- and on-site inspection with the same level of accuracy (Mcrobbie et al, 2007). The main purpose of image processing, which uses algorithms for digitization, is to obtain high-quality images and improve image interpretation. Edge detection is an image processing and computer field vision technique that locates and identifies sharp discontinuities in an image. The technique is a popular, useful approach for image segmentation (Nadernejad et al, 2008),(Uemura etal, 2011) that distinguishes objects from their backgrounds (Genasa et al, 2010). Wang et al. introduced edge detection as an image simplification technique to reduce noise and remove unnecessary objects from images(Wang et al, 2012). Abrupt pixel intensity changes normally indicate boundaries, which are useful for image segmentation matching (Bhardwaja, 2012) between objects and their backgrounds. Edge detection, or thresholding on extreme local intensities, is used for image preprocessing and highlighting hyperbola regions on GPR images. However, edge detection outcomes can be noisy and blurry (Kaur, 2016). But, in spite of issues associated with edge detection techniques specified in some studies, it is used in this study to demonstrate that the problems do not apply to all GPR images

Automatic rebar detection in GPR images uses neural network fuzzy logic (Wang et al, 2012) or template matching (Wang et al, 2012), (Simi et al, 2012),(Lewis et al, 1995). Recently, rebar detection in GPR images has also used neural network machine learning methods (Shaw et al, 2005), (Gamba et al, 2000), (Al-nuaimy et al, 2000),(Singh et al, 2013). The most functional edge detectors include those developed by Sobel, Prewitt, Canny, and Roberts, which accurately detect edges using maximum and minimum intensity values in the image (Bhardwaja et al, 2012). The Sobel edge detector can generate gradient images (Boyat et al, 2015). Image edge detection normally uses threshold values, to which the gradient image is very sensitive. MATLAB has implemented an edge detector operator, based on the root mean square, that can estimate image noise (Bhardwaja et al, 2012).

2 RESEARCH METHODOLOGY

Figure 2 illustrates the methodology used in this study

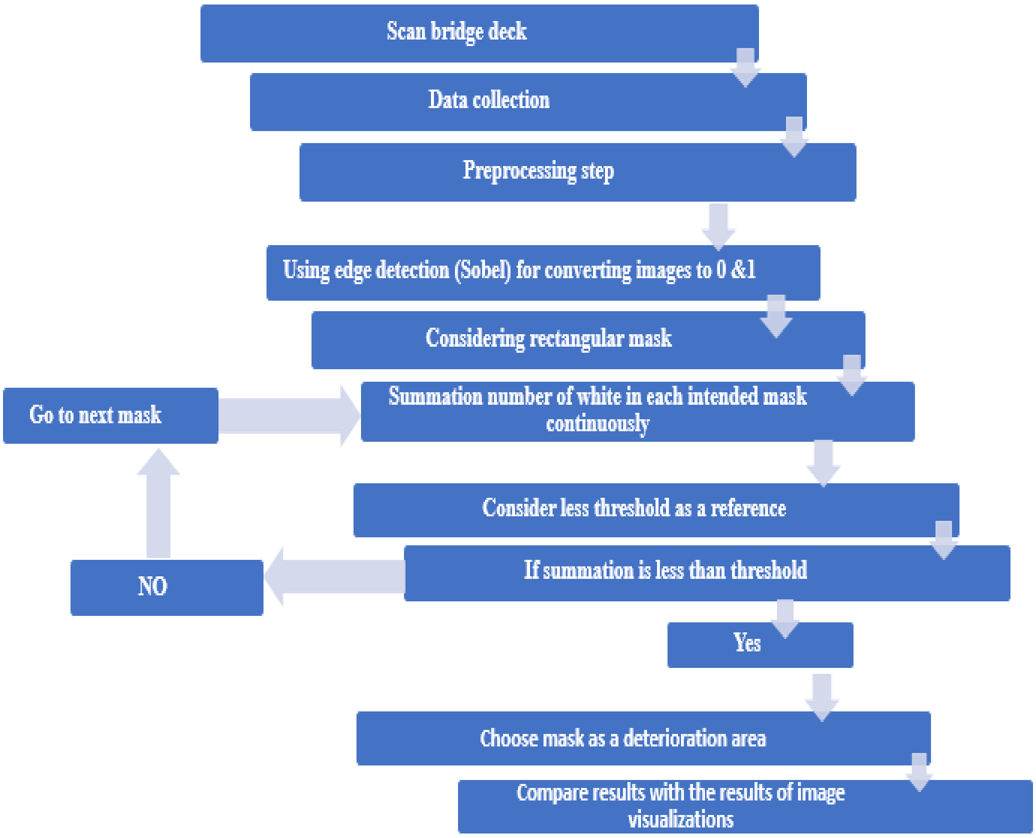


Fig. 2: Hierarchy of steps in this study

During bridge deck condition assessment, GPR scans are limited to width and height, which requires many scans. The GPR device usually collects data in parallel directions at a distance of 2 feet, so 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 travelling 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 takes 30 minutes. After data collection, the weak quality of the raw GPR images requires preprocessing techniques such as filtration and migration. Each raw GPR image has some noise resulting from environmental complexity and interference from other nearby electromagnetic activity, such as that from cell towers. “Noise” indicates the existence of any undesirable or unwanted objects or information in an image that directly affects artifacts, unrealistic edges, unseen lines, and corners; blurs objects; and disturbs background scenes (Boyat et al, 2015). The image processing technique in this paper is based on MATLAB software. This technique offers some preprocessing capabilities for removing noise and increasing GPR image quality. There are some filters for removing noise in the image such as the Gaussian filter, median filter, low pass filter, high pass filter and so on, but, among all of them, the Gaussian filter has been the most effective for removing noise on GPR images. Gaussian filtering operates as a point spread function using convolution. The image is stored as discrete pixels, which are then completely integrated with Gaussian values. After noise removal, the Sobel edge detection operator, which best clarifies the boundaries of hyperbolae, distinguishes the object from its background. The Sobel operator is a discrete differentiation operator that can compute an approximation of the image intensity function gradient.

As the output image shows, each pixel has a value of either 0 or 1. In the images, 0 refers to the black pixels, and 1 refers to white pixels, so in the area of deterioration the number of white pixels is significantly less than that of other pixels. Between two adjacent pieces of rebar are black pixels and black columns that show no deterioration, which necessitates creating a rectangular mask with considerable image width and total height. The summation of white pixels is implemented in the whole image through the intended mask: in other words, summation is performed in each rectangular mask in that part of the image. Reducing threshold as a reference for comparing summations of white pixels with that threshold is inevitable. If the summation in the rectangular mask is less than the threshold, that area is chosen as an area of deterioration; if not, the next rectangular mask should be scanned until the whole width of image is investigated. Finally, after all processes have been completed, the areas of deterioration have been identified.

3 CASE-STUDY AND MODEL IMPLEMENTATION

In this study, we used a case study case study to validate a novel algorithm for finding areas of deterioration in GPR images and compare visualization technique performance. A GSSI GPR device with a 1.5 GHz antenna scanned a bridge deck located in Iowa. All bridge scans were performed with this algorithm; Figure 3 shows one as an example. Each scan is shown as an image after a preprocessing technique, such as Gaussian filtering, removed any noise in the image. Then the edge detection operator, the other function of image processing, highlighted the objects' boundaries in the GPR image (Figure 4). As Figure 5 shows, smaller summations of white pixels (number of 1) in each rectangular mask appear as deterioration areas in that scan; five masks have been selected. The algorithm marked the selected mask in the image as an area of deterioration, arranged as shown (Figure 6). In Figure 7, an analyst marked areas of deterioration in a visualization. Comparing Figures 6 and 7 shows that the algorithm can interpret GPR images and, as a visualization technique, mark the areas of deterioration accurately.

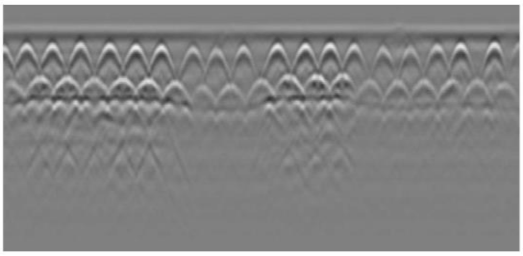
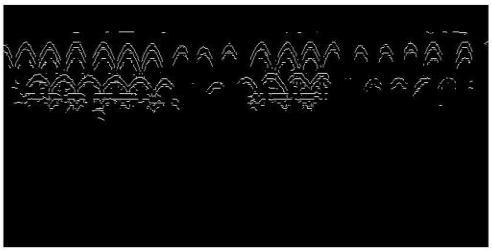


Fig. 3. Raw GPR image



Pixel info: (X, Y) BW

Fig. 4. GPR image after edge detection

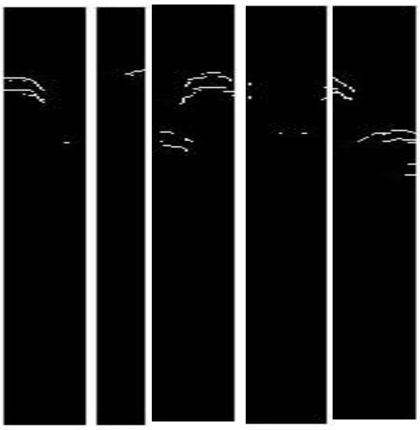


Fig. 5. Chosen rectangular mask as an area of deterioration

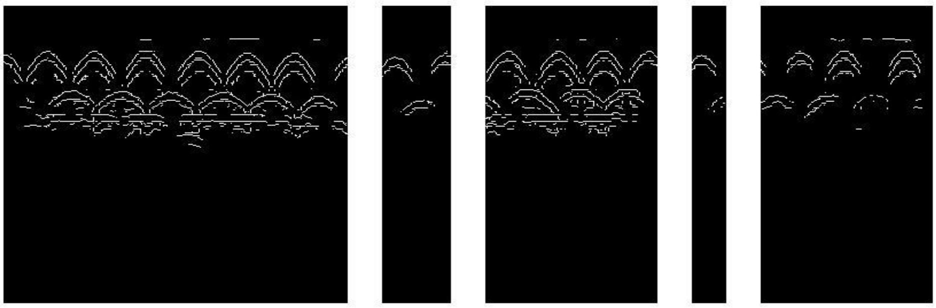


Fig. 6. Image with area of deterioration marked by the algorithm

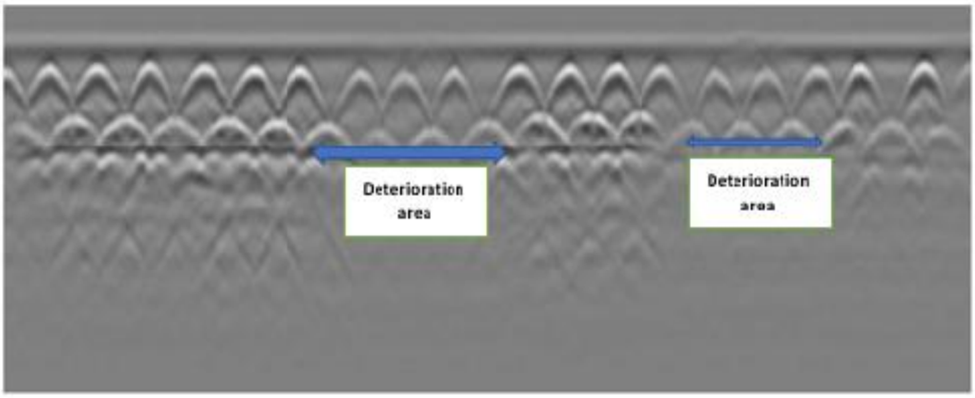


Fig. 7. Detection of deterioration areas in the image through visualization technique

4 CONCLUSION

GPR is an effective, nondestructive tool for bridge deck condition assessment. Real GPR images contain noise because of environmental complexity and interference from other surrounding radar; a MATLAB processing technique can remove noise and increase image quality using Gaussian filtering in the preprocessing phase. Interpretation of GPR images through visualization is time consuming and labor intensive, so automating the visualization process for GPR image interpretation increases efficiency. After visualization, analysts marked the attenuation area over the rebar mat as an area of deterioration, but doing this for all bridge scans takes time, whereas automation interpretation can mark any attenuation area for all scans in a few seconds. A rectangular mask with specific width and height has been created for scanning all images, and all white pixels have been summed in that intended mask. For comparison, lower treshold should be considered. Then, if summation in each intended mask does not reach the threshold for selecting that mask as an area of deterioration, the algorithm can investigate all image pixels in less than a minute. After validating the algorithm through a comparison with a scan of a real bridge in Lowa State as a case study, we have concluded that this algorithm's result is 100% identical to the result of GPR image interpretation using a visualization technique.

5 REFERENCES

Abudayyeh, O., M. Al Bataineh, and I. Abdel-Qader, "An imaging data model for concrete bridge inspection," Advances in Engineering Software, Vol. 35, 474–480, 2004

Al-Nuaimy.W,(2000) "Automatic detection of buried utilities and solid objects with GPR using neural networks and pattern recognition," J. Appl. Geophys., vol. 43, nos. 2–4, pp. 157–165,

Bhardwaja,S and Mittalb,A.(2012)"A Survey on Various Edge Detector Techniques''.Procedia Technology. Published by Elsevier Ltd .220 – 226.

Bisby, L.A. (2006). "An introduction to life cycle Engineering & Costing for innovative infrastructure", (ISIS) Canada Research Network, Department of Civil Engineering, Queen's University.

Boyat.K, Kumar Joshi.B . April 2015. ''NOISE MODELS IN DIGITAL IMAGE PROCESSING''. An International Journal Signal & Image Processing (SIPIJ) Vol.

Cardimona, S., Willeford, B., Wenzlick, J. and Anderson, N.(2001). Bridge Decks Condition Studies in Missouri Utilizing Ground Penetrating Radar: RDT 01-012. Jefferson City, MO: MoDot.

Chen, P. H.,and Chang, L. M. (2002), "Computerized bridge coating defects assessment using Neuro-Fuzzy Thresholding Method'' ,International Symposium on Automation and Robotics in Construction, Washington, U.S.A, 331-336

Federal Highway Administration (FHwA). (2009). "National bridge inventory (NBI)." 〈http://www.fhwa.dot.gov/bridge/deficient.cfm〉 (Oct. 7, 2010).

Gamba.P and Lossani.S., (2000)"Neural detection of pipe signatures in ground penetrating radar images," IEEE Trans. Geosci. Remote Sens., vol. 38, no. 2, pp. 790–797, Mar. 2000.

Genasa, P., Rjini, V., and Rajkumar, R.I. (2010), "Segmentation and edge detection of color images using CIELAB color space and edge detectors'', Emerging Trends in Robotics and Communication Technologies (INTERACT).Chennai.393-397

Hugenschmidt, J. (2002), "Concrete bridge inspection with a mobile GPR system'', Construction and Building Materials. 147–154

Kaur,p. Dana,J. Romero,F.Guunski,N.(2016). "Automated GPR Rebar Analysis for Robotic Bridge Deck Evaluation''. IEEE TRANSACTIONS ON CYBERNETICS, VOL. 46, NO. 10.

Lee,J. H., Lee, J. M., Park ,J.w., and Moon,Y.S.(2008). "Efficient algorithm s for automatic detection of cracks on a concrete bridge'',The 23rd International Technical Conference on Circuits, System, Computers and Communications.Shimonoseki,Japan,1213-1216.

Lewis.J.P,(1995) ."Fast normalized cross-correlation," Vis. Interf., vol. 10, no. 1, pp. 120–123.

McRobbie S., Lodge R., and Wright A., (2007), automated inspection of highway structures – Stage 2, PPR 255, Transportation Research Laboratory, UK

Nadernejad, E., Sharifzadeh, S., and Hassanpor, H. (2008), "Edge detection techniques:Evaluations and comparison'', Applied Mathematical Sciences, 2(31), 1507-1520

Nguyen, T. S., Avila, M., and Stephane, B. (2009). "Automatic detection and classification of defects on road pavement using anisotropy measure", 17th European Signal Processing Conference, Glasgow, Scotland, 617-621

Romero, F.A.(2003), New York State Department of Transportation Ground Penetrating Radar Demonstration on Route 378 Bridge over D&H Railroad and Route 66 Bridge over Kinderhook Creek, October .

Shaw.M.R, Millard.S.G, Molyneaux.T.C.K, Taylor.M.J, and Bungey.J.H,(2005) "Location of steel reinforcement in concrete using ground penetrating radar and neural networks," NDT&E Int., vol. 38, no. 3, pp. 203–212.

Shin,H and. Grivas ,D.A.(2003). "How accurate is Ground-Penetrating Radar for bridge deck condition assessment?'', Transportation Research Record 1845 _ 139 Paper No. 03-4463.

Shuai, L . ,Yuan, C.,Liu, D.,Cai, H.(2016). "Integrated Processing of Image and GPR Data for Automated Pothole Detection''. Journal of Computing in Civil Engineering, © ASCE, ISSN 0887-3801.

Simi.A., Manacorda.G, and Benedetto.A,(2012) "Bridge deck survey with high resolution ground penetrating radar," in Proc. 14th Int. Conf. Ground Penetrat. Radar (GPR), Shanghai, China, ,pp. 489–495

Singh.N.P and Nene.M.J, (2013)"Buried object detection and analysis of GPR images: Using neural network and curve fitting," in Proc. Annu. Int. Conf. Emerg. Res. Areas Int. Conf. Microelectron. Commun. Renew. Energy (AICERA/ICMiCR

Tarussov, A .Vandry ,M. Haza, A . (2013), "Condition assessment of concrete structures using a new analysis method: Ground-penetrating radar computer-assisted visual interpretation", Construction and Building Materials journal, Vol: 38, P: 1246-1254.

Uemura,T., Koutaki,G., and Uchimura, K.(2011), "Image segmentation based on edge detection using boundary code'', International journal of Computing, Information and Control.97(10),6073-6083.

Vaghefi, kh., Oats, R., Harris, D. Ahlborn, T. Brooks, C. Endsley,, R.Roussi, C. Shuchman ,R. Burns ,J. Dobson ,R. (2012), "Evaluation of Commercially Available Remote Sensors for Highway Bridge Condition Assessment", American Society of Civil Engineers. Journal of Bridge Engineering, Vol. 17, No. 6, November 1, 2012. PP: 886-895.

Wang, Zh. Zhou, M. Zhai, J. Fang, T. (2012), "Automatic Detection of Bridge Deck Condition from Ground Penetrating Radar Images", IEEE Transactions on Automation Science and Engineering, VOL. 8, NO. 3, JULY 2011