ROTATION AND SCALE INVARIANT TEMPLATE MATCHING APPLIED TO BURIED OBJECT DISCRIMINATION IN GPR DATA

Ahmet Burak Yoldemir and Mehmet Sezgin

TÜBİTAK UEKAE,
Gebze, Kocaeli, TURKEY

1. INTRODUCTION

In this study, a template matching approach to buried object discrimination problem is proposed over ground penetrating radar (GPR) B-scan images, which is an improved version of [1]. The technique is scale invariant, which compensates for the change in the swinging speed of the detector. It is also rotation invariant to some extent, which reduces the number of templates to be used by compensating for the change in the scanning direction.

The conventional method for template matching is correlating a template t with an input image f. For the sake of robustness, the correlation values are also normalized, which is given by the formula:

$$h(u,v) = \frac{\sum_{x,y} f(u+x, v+y)t(x,y)}{\sqrt{\sum_{x,y} f^2(u+x, v+y))}} \tag{1}$$

where (u, v) represents the image coordinate and (x, y) is the template coordinate. The summation is over all template coordinates. However, using normalized correlation introduces a high burden to the system, which forces the researchers to come up with acceleratory modifications. The intuitional remedy is binarizing the template and query images, when the problem specifications allow. In addition to binarization, one can use a light-weight formula which approximates (1). For this purpose, a fast template matching method is presented in [2], which relies on integral images. In [3], computational cost of template matching is reduced via Haar-like box features. In [4], another similarity measure is defined using binary logical operators. There exist several studies working in the frequency domain to accelerate the process (e.g., [5]).

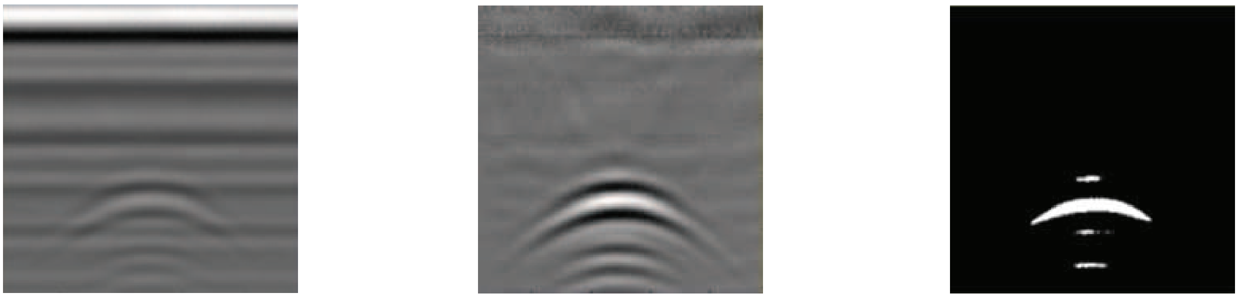
2. PROPOSED METHOD

2.1. Background subtraction

Prior to applying template matching, we use background subtraction which reveals the signatures of the buried object more clearly. If it is guaranteed that the starting location does not contain any target signature, a predefined number of A-scan signals can be averaged and subtracted from each following A-scan, which will reveal target signature [6].

2.2. Binarization

Thresholding is a well researched topic and there exist several thresholding algorithms, a survey of which can be found in [7]. The thresholding method should be chosen carefully according to problem specifications. For example, one may need adaptive thresholding for removing illumination artifacts. As our problem is underground inspection, a global threshold method will suffice. Upon implementation of several thresholding algorithms given in [7], we decided that Kittler and Illingworth's minimum error thresholding is convenient for our purposes. The method defines segmented region according to image histogram statistics and cumulative probability distribution of image intensity. A typical B-scan, result of background subtraction and binarized image are given in Fig. 1.



(a) Original B-scan (b) Background subtracted (c) Binarized B-scan

Fig. 1. A typical B-scan and preprocessing steps.

2.3. Template matching

After binarizing the input image, we need an efficient correlation measure. For this purpose, we use the method appeared in [4], which is an effective similarity feature approximating correlation for binary images:

$$s(A,B) = \frac{\sum A \wedge B}{1 + \sum A \oplus B} \tag{2}$$

where A and B are input images to be compared, $s(A,B)$ is the measure of similarity between input images, $\wedge$ is the logical AND operation and $\oplus$ is the logical XOR operation. The summations just give the number of pixels of value 1 in the resulting binary image. As is intuitive, a large value of $s(A,B)$ might indicate the presence of a buried object at the inspected region.

The swinging speed of the detector head causes the target signatures to differ. If the detector is moved slowly, response from the target can be observed in a large number of A-scans, whereas if the detector is moving fast, the target response quickly vanishes. Moving the detector faster can be thought as removing some of the columns from the B-scan images. This causes the B-scan to shrink in the horizontal direction. Moving the detector faster, on the other hand, is analogous to stretching the B-scan in the horizontal direction. In Fig. 2, two B-scans of the same object (which is an M7A2 surrogate antitank mine), which are taken at different detector speeds are provided. Specifically, while gathering the B-scan to the left, the detector speed was twice as fast as the detector speed while the B-scan to the right is taken.

(a) B-scan with fast detector speed (b) B-scan with slow detector speed

Fig. 2. Two B-scans taken at different scanning speeds.

To compensate for this change, the system must be scale invariant. Specifically for our problem, this scale invariance is needed in the horizontal direction only. For this purpose, there are two options. Copies of the target pattern can be constructed at different scales, and similarity of each with the query image can be calculated. Alternatively, a target pattern of fixed size can be compared with several copies of the image represented at correspondingly reduced resolutions. As shown in [8], second approach is much more efficient. This second technique, so-called the Gaussian pyramid, consists of low-pass filtering and subsampling the image at each level to obtain the next pyramid level. Low-pass filtering is used to eliminate the potential aliasing effects. As mentioned before, in our problem, scale invariance in horizontal direction is sufficient. Hence, at each step, only the resolution in the horizontal direction is reduced. We call this method as the *modified Gaussian pyramid*. Using modified Gaussian pyramid allows us to minimize the effect of changes in the swinging speed of the detector in an efficient manner.

The swinging direction of the detector also affects the target signature. Two examples clarifying this phenomenon are given in Fig. 3. To be able to find targets scanned in different directions, one needs to create different templates for different scanning directions. In [1], this was done using 4 templates. In this study, we propose using 2 templates, which are for horizontal and vertical scans, where the templates are allowed to rotate. This rotation accounts for many different directions, using a smaller number of templates. Nature of the problem limits the maximum rotation deviation, hence this rotation invariance does not introduce a heavy burden to our system. In our implementation, maximum possible rotation is 20 degrees for each template.

(a) First B-scan (b) Second B-scan

Fig. 3. Two B-scans taken at different scanning directions.

3. SUMMARY

The proposed method consists of several steps, which can be summarized as follows: The input image is converted to a binary image using Kittler and Illingworth's minimum error thresholding. Then, using the modified Gaussian pyramid, the templates for different objects are compared to different resolutions of the input image according to (2). The templates are allowed to rotate to a certain extent.

Binarization, modified Gaussian pyramid and the logical approximation to normalized correlation are all techniques that help us to reduce the burden of template matching. Rotation step is also simplified as maximum rotation possible is greatly limited by the problem specifications.

Compared to [1], this study is much more efficient in terms of computational cost thanks to aforementioned techniques. We reduce the number of templates, and this system is more robust against changes in the swinging direction and speed of the detector, which are very common in handheld detector systems.

4. REFERENCES

[1] M. Sezgin, "Two dimensional template matching method for buried object discrimination in GPR data," in *Proceedings of the SPIE on Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XIV*, R. S. Harmon, J. T. Broach, and J. H. Holloway, Eds., 2009, vol. 7303.

[2] H. Schweitzer, J. W. Bell, and F. Wu, "Very fast template matching," in *ECCV '02: Proceedings of the 7th European Conference on Computer Vision-Part IV*, London, UK, 2002, pp. 358–372, Springer-Verlag.

[3] F. Tang and H. Tao, "Fast multi-scale template matching using binary features," in *WACV '07: Proceedings of the Eighth IEEE Workshop on Applications of Computer Vision*, Washington, DC, USA, 2007, p. 36, IEEE Computer Society.

[4] D.-S. Jun, S.-G. Sun, and H. Park, "Automatic target detection using binary template matching," *Optical Engineering*, vol. 44, no. 3, 2005.

[5] S.L. Kilthau, M.S. Drew, and T. Moller, "Full search content independent block matching based on the fast fourier transform," in *Proceedings of the 2002 International Conference on Image Processing*, 2002, vol. 1, pp. 669–672.

[6] D. J. Daniels, *Surface Penetrating Radar*, IEE Press, London, UK, 2. edition, 2004.

[7] M. Sezgin and B. Sankur, "Survey over image thresholding techniques and quantitative performance evaluation," *Journal of Electronic Imaging*, vol. 13, no. 1, pp. 146–168, 2004.

[8] E. H. Adelson, C. H. Anderson, J. R. Bergen, P. J. Burt, and J. M. Ogden, "Pyramid methods in image processing," *RCA Engineer*, vol. 29, no. 6, pp. 33–41, 1984.