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Extraction of the Straight Line Segments from the Noisy Images as a Part of Pattern Recognition Procedure

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Abstract

The automated analysis of the images is of great importance today in many applications. In ultrasonic nondestructive evaluation of materials, the B- and C-scanning generates two-dimensional images which often require automated interpretation. Such images are often noisy and low-contrast. They are formed by combination of multiple ultrasonic waveforms obtained at different moments of investigation process or at different locations of the object of interest. The straight line segments are often formed on such images as a reflection of some physical phenomena taking place in the material. Such lines can sometimes be considered as the elements of more complex patterns when some a priory knowledge allows one to break the pattern into logical sub-elements. The suggested technique provides the way to recognize very low-contrast line segments on acoustical and other images when signal to noise ratio (SNR) is 1 and lower. At such SNR, the separation of real line from the noise artefacts becomes a challenging problem. The proposed technique provides the way of dealing with such problems by obtaining redundant amount of data from the area of interest using Radon transformation as the key part of the procedure.

Keywords: Radon transform, two-dimensional filter.

1. Introduction

Many two-dimensional images generated with ultrasonic and other testing techniques, images of the cities from the air etc. contain straight line pieces, or segments. On the airborne photos they represent the roads, channels and other artificial objects. On the images generated by the material testing equipment such lines could represent the physical processes or interfaces between contacting surfaces. As long as today's technology allows one to create an enormous amount of data related to the problem of interest, it is often impossible for a human to process it in the required time intervals. In many cases the interpretation of the image needs to be done within milliseconds after the image is acquired and a decision is to be made regarding the further actions. The processes need to be automated to deal with such situations. Today, in many applications, the computers are set up to automatically recognize the pattern on the image, interpret it and sometimes based on the interpretation to make an appropriate decision.

In many cases the straight line elements of possibly more complex patterns need to be extracted from the image to provide a physical, geometric or other interpretation of the image data. Often, such lines are hidden in the noise, overlap with other image elements. For example, Figure 1 presents a sub-image of the bigger image acquired during ultrasonic real-time testing of the resistance spot weld growth. The straight segment indicated with the arrow reflects the dynamics of the spot weld development and is a very important feature in the nugget quality characterization. The image is composed of multiple waveforms obtained during testing which lasts only tens of milliseconds [1, 2]. The intensity of the line is much lower than that of the other image elements which reduces the possibility to detect the line. Still, such straight lines possess the power the other picture elements do not have: these are the ordered structures. For such lines the Radon transform could be applied to detect their presence even when the SNR is very low. The original image can be pre-processed before doing the analysis but often the unwanted picture elements can not be removed completely. In noisy images the processing of the Radon transform itself is often required to have the opportunity to automatically detect the presence of the line of interest.

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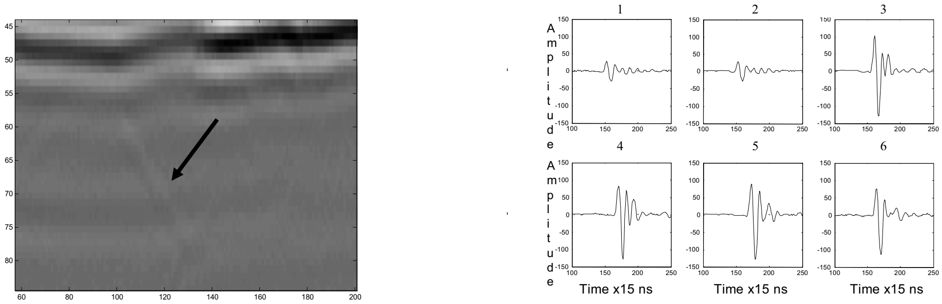

Figure 1. Example of the image with the straight line (left). The picture is the acoustical B-scan representing the dynamics of resistance spot weld growth. Every vertical line of the image is a separate oscillogram (right).

2. How the Radon Transform Works

If the image is gradually rotated around its center and projected on the fixed line, one will get a set of projections at different angles. The projections can be put together one after another to form a two-dimensional picture. On the x-axis there will be the degree of rotation, on the y-axis is the projection corresponding to that angle. **Erreur ! Source du renvoi introuvable.** shows the square with a straight line at 22 degrees with respect to the negative y-axis. Numerically, the black background of the image is composed of zeros and the line is composed of ones. Gradual rotation of this image clockwise around its center from 0 to 90 degrees and projection on the horizontal axis generates a Radon transform (RT) picture shown at **Erreur ! Source du renvoi introuvable.**. This transform shows a maximum at 22 degrees. Vertical axis is the projection whose length is $\sqrt{2}$ longer than the side of the square. The position of the maximum in Radon transform allows one to find the direction of the line (angle) in the image. Position at the projection axis (y-axis) defines the distance D of the line from the center of the image, see **Erreur ! Source du renvoi introuvable.**. Projection of the image on the horizontal line (plane of projection) in this figure creates one vertical line of data of the RT of **Erreur ! Source du renvoi introuvable.**. When image is rotated by angle β the transform will have a maximum corresponding to the strongest projection of the image line. Thus, the Radon transform can provide enough information to draw a line through the image along the discovered line.

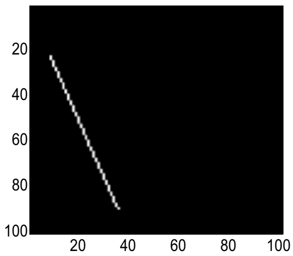

Figure 2. A 100x100 square with straight line at 22 degrees with respect to the -y-axis.

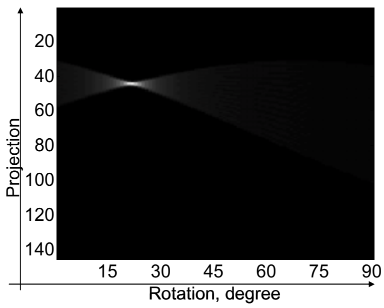

Figure 3. Radon transform of the image with projection peak at 22 degrees.

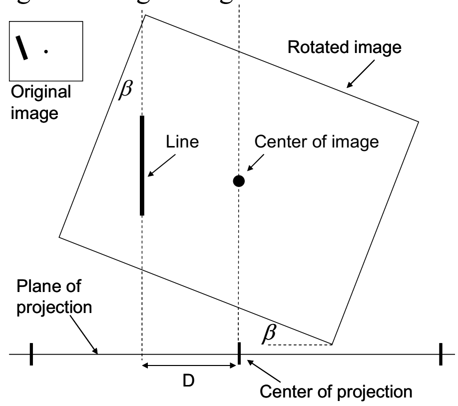

Figure 4. Image rotated by angle β .

The choice of the square (or rectangular) image is not the best one as long as the RT of the square is by its nature an uneven image, see Figure 5. Figure 6 shows the transform of the same square but with the line going through the square. In this case the original image is the same as in the **Erreur ! Source du renvoi introuvable.**, while numerically, the background is composed of ones and the line is composed of twos. On the Figure 6 the arrow shows the local maximum corresponding to the location of the line. But the center of the Radon image could be brighter as long as projection along the diagonal of the square (at 45 degrees) can easily exceed the amplitude of the line projection. The automatic peak (or maximum) detection could grab the center of the image instead of the peak pointed with the arrow (the one we need to detect). To fight it the image can be made circular to have even amplitudes at any rotation angle, Figure 7, 8.

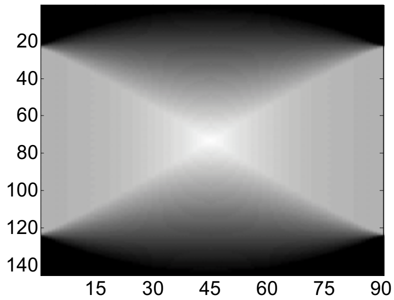

Figure 5. Radon transform of the even square of size 100x100.

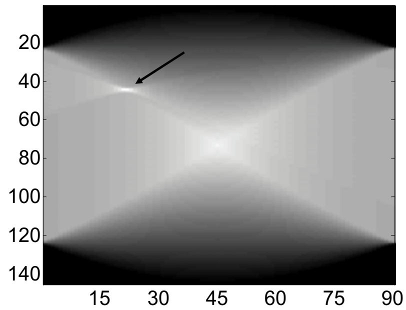

Figure 6. Radon transform of the even square with the straight line segment.

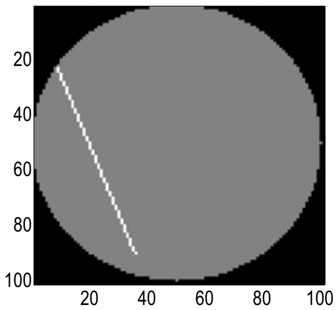

Figure 7. Line in the circular image.

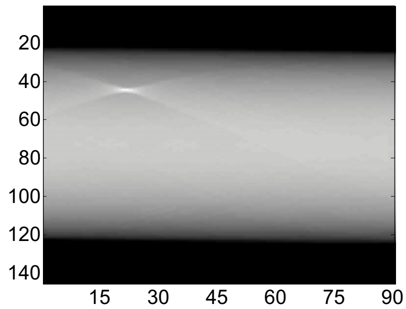

Figure 8. Radon transform of the circular image with the peak corresponding to the straight line at 22 degrees.

3. Transforms of the Noisy Images

The pictures shown in the previous section can be considered as examples for RT demonstration and present mostly academic interest. Such clear pictures with only a single straight element rarely happen in practice. In many practical applications, noises are an inalienable part of the image. In real images the signal to noise ratio could be of the order of 0.1-0.01. The lines of interest can be hidden in the more powerful signals. On Figure 9 one can see the circle with background modulated by sine function and a straight line of 0.2 of the sine amplitude. The corresponding RT is shown in Figure 10. In this case the picture becomes much more complicated for automatic analysis. There are a lot of local maxima, and their positions are unpredictable. If the amplitude of the line or its length slightly decreases the RT line peak will be below other local maxima. Its positioning will become an unreliable procedure.

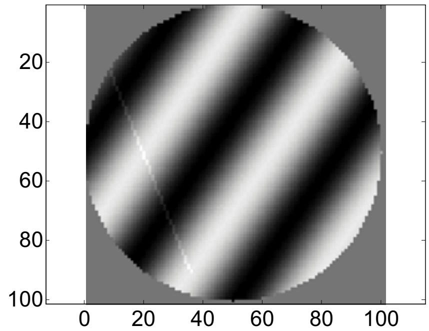

Figure 9. Circular image modulated by sine function and a line of 0.2 of the sine amplitude.

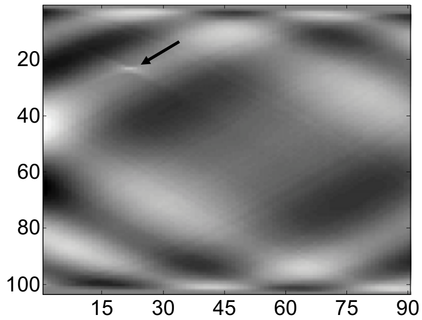

Figure 10. Radon transform of the image.

One of the possible solutions is filtering the RT image [3]. In many cases the peak of interest is smaller than other peaks and a 2-D high-pass filtering could be applied for the RT image. The choice of specific cutoff frequency is up to the application. For the given ultrasonic scans the following 2-D Remez filter was applied: order - 30; frequency response - [0 0.4 0.6 1] of Nyquist frequency corresponds to the amplitudes [0 0 1 1]. This is the high-pass filter with cutoff at 0.5 of the Nyquist frequency and the slope going from 0.4 Hz with zero response up to 0.6 Hz with unity response, see Figure 11. The result of filtering is shown at Figure 12. For comparison one can draw a vertical section of the RT image at 22 degrees – through the maximum. The upper plot of the Figure 13 shows the vertical image profile of the Figure 10 at 22 degrees; the lower plot is the vertical profile of the filtered image of the Figure 12. The arrows point at the peak of interest.

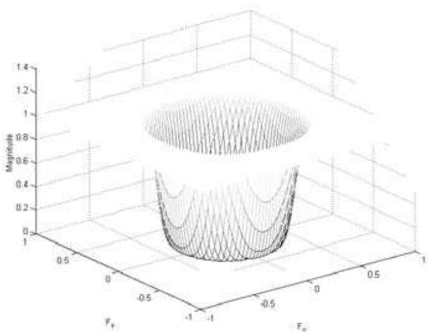

Figure 11. High-pass 2-D filter with 0.5 Nyquist cutoff frequency.

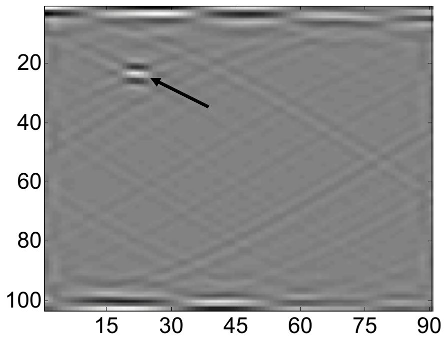

Figure 12. RT image filtered with high-pass filter.

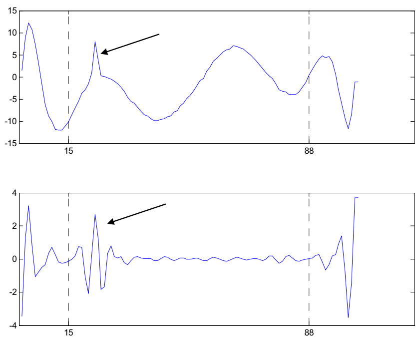

Figure 13. The vertical sections of the RT images at 22 degrees before (upper) and after (lower) filtering.

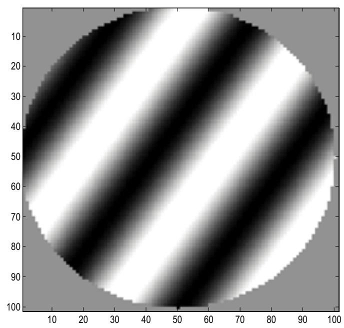

Figure 14. Circular image modulated by sine function and a line of 0.02 of the sine amplitude.

When the amplitude of the straight line is of the order of 1-5% of the noise amplitude, some additional processing is required for automatic location of the peaks. The image on the

Figure 14 has the line of 2% amplitude running the same way as in the previous, 20%, example. It can hardly be seen on the image. Still, the RT processing is capable to detect the line. On Figure 16 one can see the original RT image; the peak is too weak to be visualized. Figure 16 shows the results after the high-pass filtering .Now some weak "bump" can be recognized, and it is pointed to by the arrow. Still, the lines going approximately at 45 and -45 degrees are too strong. Such lines can be relatively easily removed using another 2-D filter with selective directional effect. Its action is aimed at removing the lines going approximately at +-45 degrees. The filter is shown at **Erreur ! Source du renvoi introuvable.**, and the result of its action on the previously filtered RT image is at the **Erreur ! Source du renvoi introuvable.**. The arrow points to the preserved and still detectable peak determining the location and orientation of the line segment on the original ultrasonic image. **Erreur ! Source du renvoi introuvable.** demonstrates the vertical profiles of the initial RT image, high-pass filtered and then selectively filtered ones - upper, middle and lower plots correspondingly. Even for the 2% amplitude the line can be successfully detected. **Erreur ! Source du renvoi introuvable.** shows the vertical sections of the RT images: original, high-pass filtered and diagonally filtered. The peak can be easily localized after the second filtering.

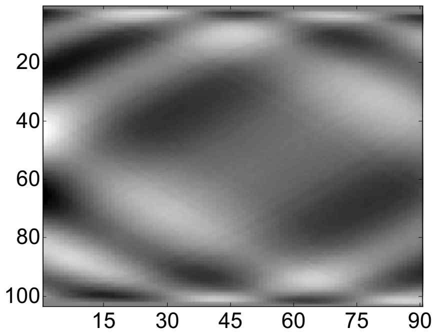

Figure 15. The unprocessed RT of the image with 2% intensity line.

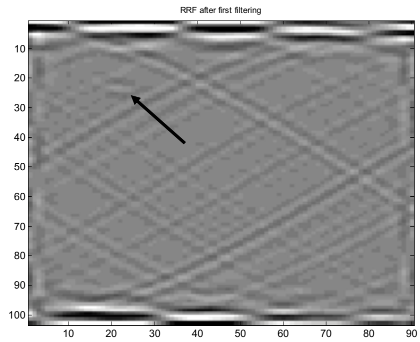

Figure 16. RT of the image with 2% line filtered with high-pass filter.

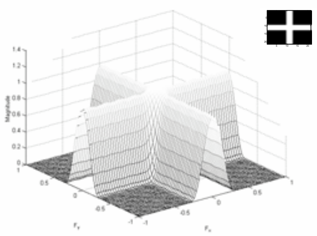

Figure 17. 3-D view of the second filter removing the near-diagonally oriented lines; small image in the right upper corner is a 2-D view of the same filter.

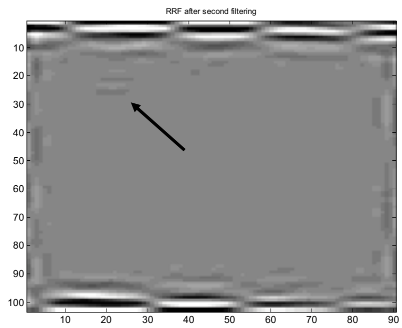

Figure 18. Results of the second filtering. Diagonal lines are removed while the useful information is preserved.

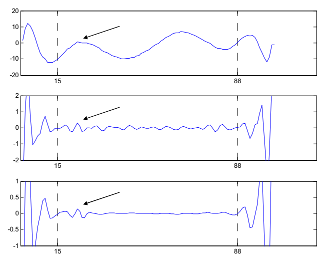

Figure 19. Image profiles of the original RT image (upper), high-pass filtered (middle) and diagonally filtered (lower) at 22 degrees. Arrow point at the place where the peak is located.

Also, studies have been made for the completely random images with line going the same way through the circular image. If the amplitude of the line is close to the random noise amplitude, the RT picture readily shows the location of the line, see Figure 20, 21. Here the line also goes at 22 degrees through the circle of random numbers and it can be seen easily. The RT picture also shows well defined spike indicated with the arrow. The situation is much worse when the line amplitude is 2-3 times lower than this. On Figure 22 one can barely see the presence of the line segment. The RT image of this circle is presented at Figure 24 and the global maximum is indicated by the arrow. This maximum will falsely define the line position leading to erroneous interpretation of the original image. Looking at a pure RT image of the straight line (**Erreur ! Source du renvoi introuvable.**) one can see that the spike defining the line position is stretched horizontally. One could employ this fact to remove the noise in RT image in the horizontal direction using horizontal low-pass filter. The filter used to process the obtained RT image is shown at Figure 23. It removes high frequencies along the horizontal direction. In this case the global maximum is positioned at the right place defining the true position of the line in the image (Figure 25).

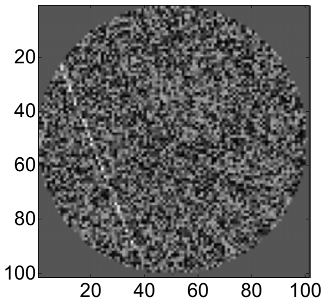

Figure 20. Line going through the circle of random numbers of amplitude in the range -0.5..+0.5. Line amplitude 0.5.

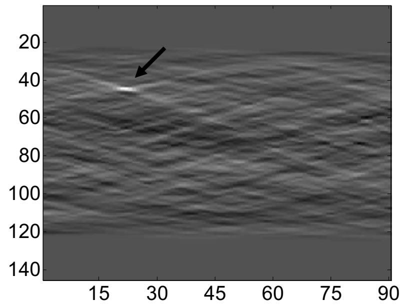

Figure 21. RT of the random image with line amplitude 0.5.

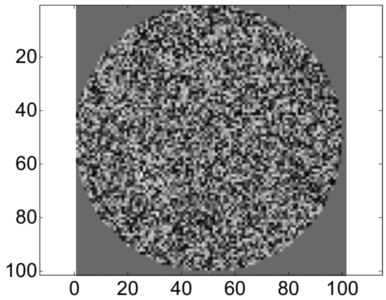

Figure 22. Line going through the circle of random numbers of amplitude in the range -0.5..+0.5. Line amplitude 0.2.

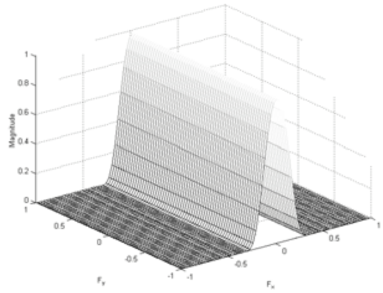

Figure 23. Horizontal low-pass filter.

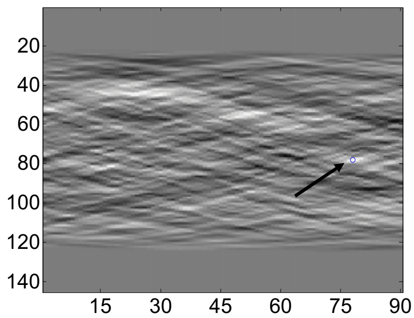

Figure 24. Original RT image with maximum in the "wrong" place.

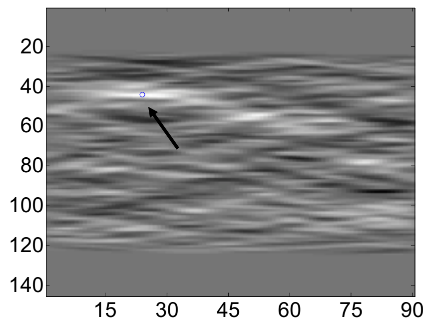

Figure 25. Horizontally filtered RT image reveals the true position of the line.

4. Conclusions

The automatic recognition of the patterns in the noisy images is a challenging task requiring a lot of efforts from the software developer. In cases when the patterns contain straight segments and their approximate position and/or orientation can be predicted, the Radon transform can significantly help define their position and orientation on the image. Preprocessing of the original image is the first thing which needs to be done before recognition process. Still, processing of the RT images is often required to be able to correctly localize the position of the lines of interest. In many cases the search of the peaks on the RT images do not need to be done in the range of 0..90 degrees. If the orientation of the line is approximately known the search can be run in the lower range of angles, thus looking for the local maximum instead of the global one. This also increases robustness of the technique eliminating the possibility to falsely grab some maximum due to the side effects of filtering on the edges of the RT image.

The choice of the filters for the RT images is defined by the nature of the image. In some cases the filtering is not required at all. But when the SNR is low, the RT image processing becomes a necessary task for developing robust techniques for line detection.

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