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ROBUSTNESS OF A DFT BASED IMAGE WATERMARKING METHOD AGAINST AM HALFTONING

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Original scientific paper

In this paper the robustness of a Discrete Fourier Transform (DFT) based image watermarking scheme to amplitude modulation (AM) halftoning is evaluated. Halftoning is used for reproduction of continuous images. Thus, it is important that a watermarking method is robust to halftoning. Three different shapes of clustered dots of AM (Amplitude Modulation) halftones are used (round, ellipse and line) with five different halftone frequencies (10, 13, 15, 40, and 60 line/cm). The tests where done on a dataset of 1000 images. As the metric of robustness, watermark detection rate, distribution of detection values, and ROC (Receiver Operation Characteristic) curves were used. The results showed that the watermarking scheme is robust to halftoning for halftone frequencies greater than 15 line/cm. Also, the type of AM halftone used has almost no effect on a detection rate.

Keywords: *amplitude modulated halftoning, discrete Fourier transform, image, watermark*

Otpornost DFT metode označavanja slika na rastriranje

Izvorni znanstveni članak

U ovom radu je evaluirana otpornost na rastriranje metode označavanja slika bazirane na diskretnoj Fourierovoj transformaciji (DFT). Rastriranje se koristi za reprodukciju višetonskih slika. U istraživanju je korišten set od 1000 slika. Za rastriranje su korištena tri različita oblika rasterskog elementa (točka, elipsa i linija) i 5 različitih linijatura (10, 13, 15, 40 i 60 lin/cm). Evaluirana je vjerojatnost detekcije i distribucija postignutih vrijednosti detekcije. Rezultati su pokazali da je ispitivana metoda označavanja slika otporna na rastriranje linijaturama većim od 15 lin/cm. Također, zaključeno je da oblik rasterskog elementa ima slab utjecaj na stupanj detekcije.

Ključne riječi: *diskretna Fourierova transformacija, rastriranje, slika, vodeni znak*

1 Introduction
Uvod

With today's availability of digital images, the immense leap forward in the computational power of an average computer, and new technologies that enable misuse of digital images, there is a growing need for watermarking methods. This need has been met with a limited success by scientists and researchers, and there are many different approaches to the problem of digital image protection.

One of the most popular approaches is the implementation of the watermark in the Fourier transform domain. This approach has two advantages in comparison with the spatial domain methods. First, it is translation invariant and rotation resistant, which leads to strong robustness to geometric attacks, and second, the energy of the watermark is distributed over the entire image after the transformation back to the spatial domain, which enables the implementation of stronger watermarks with less perceptual impact. On the other hand, according to Raja et al. fast Fourier transform (FFT) methods introduce round-off errors, which can lead to loss of quality and errors in watermark extraction [1]. However, Cheddad et al state that this disadvantage is much more important for hidden communication than for watermarking [2].

Because of its resistance to geometric attacks and the distribution of energy, FFT watermarking methods are developed to create robust watermarking schemes resistant to the degradation attacks of the watermarked image in the transmission channel such as Print-scan process (PS process). The robustness of the watermarking method to PS process would enable the use of the method in the protection of the printed images, thus enabling the use of digital watermarks in the protection of analog media. However, the PS process is very difficult to model. It engenders a number of linear (translation, rotation and scaling) and nonlinear attacks (pixel distortions, and noise addition). These attacks are not only user and equipment dependent, but also time-variant [3-5]. For this reason there are few watermarking methods robust to the PS process all of which use the Fourier transform domain. Examples can be found in He and Sun [5], Pereira and Pun [6], Lee and Kim [7], and Kang et al. [8]. There are also some multiple domain methods that use the advantages of different domains to create a very robust watermarking scheme. A good example of a multiple domain method is presented in Pramila et al [9].

However, no one gave the methodological evaluation of the robustness of a Discrete Fourier Transform (DFT) based watermarking method to Amplitude Modulation (AM) halftoning. A search for the existing publications on the subject showed that there are no papers that show the influence of AM halftoning on detection rate of this kind of watermark schemes.

2 Halftoning in the PS process
Rastriranje u PS procesu

The degradation of an image due to a PS process is very hard to model. Lin et al. [10] have modeled the PS process with an Inkjet printer as the geometric distortion coupled with change of pixel values due to nonlinearity of the conventional PS system. He and Sun [5] and Solanki et al. [11] evaluated the properties of the magnitudes coefficients in the DFT domain. Poljicak et al. [12] state that the degradation of an image in the PS process for closely related colors can be modeled as additive Gaussian noise. Kang et al. [8] state that the distortion of image DFT coefficients includes both nonlinear distortion and additive random noise and geometric transformations such are rotation, translation, scaling and cropping.

Watermarking methods based on DFT are robust to PS process firstly because of the inherent resistance to rotation, scaling and translation, and secondly, according to He and Sun. [5], most relationships between DFT coefficients are preserved during PS process.

All above mentioned research used, in their models of PS process, frequency modulated (FM) halftoning method. However, to create a truly robust watermarking method that will be practical in the field of graphic technology robustness to AM halftoning must be determined.

2.1 AM halftoning
AM rastriranje

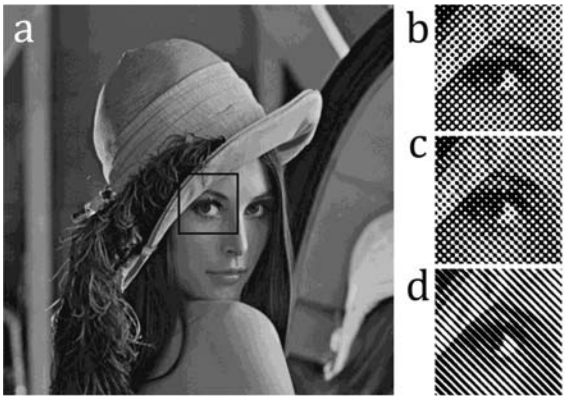

Figure 1 *Original image (a), round (b), ellipse (c), and line (d) halftone*
Slika 1. *Originalna slika (a), točkasti (b), eliptični (c), i linijski (d) raster*

Halftoning technology is mainly applied in the fields of printing devices and image displays. It is a process of transforming continuous tone images into halftone images for the devices that can only process bi-level images. The challenge of halftoning still lies in how to produce a high quality image that is visually close to its original through bi-level devices [13].

In AM halftoning, the density of dot clusters, which is defined as the number of lines per unit length, is fixed. Tone rendition is achieved by varying the size of each dot. The most commonly used AM halftoning algorithm is clustered dot screening [14]. Cluster dot screening has the advantages of low computational load and stable dot formation. One drawback of cluster dot screening is its limited ability to render fine detail. Moreover, the regular dot placement also makes it vulnerable to moiré patterns when periodic patterns in the image are similar to the clustered dot frequency [15].

The AM halftoning process is based on threshold halftoning which can be defined as:

$$H(i,j) = \begin{cases} 1 & \text{if} \quad I(i,j) \geq T(i,j) \\ 0 & \text{if} \quad I(i,j) < T(i,j) \end{cases} \tag{1}$$

where H, I and T denote the final halftoned image, the original image and the threshold matrix respectively. The pixel value at each position (i, j) in I is compared with the corresponding position in the threshold matrix T. If this is bigger than the threshold or equal to it, then a 1 (black dot) is set at the corresponding position in the halftoned image H. Otherwise, a 0 (white dot) is set there.

Depending on the form and type of the threshold matrix the shape of clustered dot will vary (Fig 1.).

3 Watermarking method
Metoda označavanja vodenim znakom

3.1 Encoding
Enkodiranje

The watermark is embedded in a cover work in the magnitude coefficients of the Fourier domain. The block diagram of the encoder is shown in Fig. 2. First, luminance values of the cover work are transformed in the Fourier domain. Then the low frequency magnitude coefficients of the transform are moved to the centre. This enables the control in what frequencies the watermark will be embedded by controlling the radius of the implementation. Third, using the secret key k that represents the seed of the pseudo-random (PRND) number generator, the row vector v with l binary elements is obtained. After that, optimal radius of the implementation r_0, is determined. Optimal radius of the implementation is found by iterative search of the radius for which peak signal to noise ratio (PSNR) value (2) is maximized.

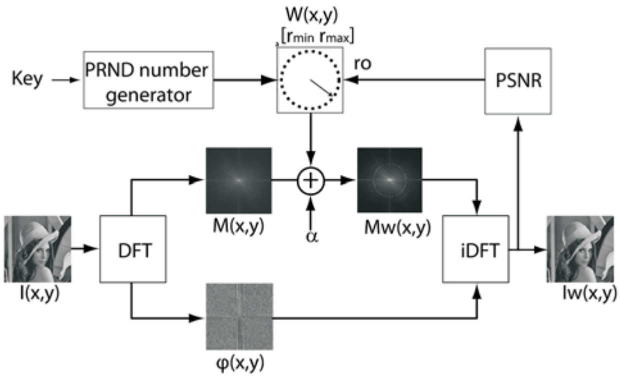

Figure 2 *Block diagram of the encoder*
Slika 2. *Blok dijagram enkodera*

PSNR, albeit old, is still a very common metric for quality assessment in image processing. It is defined as:

$$PSNR = 10 \cdot \log\left(\frac{MAX^2}{MSE}\right), \tag{2}$$

where MAX is the highest possible value in an image (usually 255), MSE denotes Mean Squared Error which is given as:

$$MSE = \frac{1}{mn}\sum_{x=0}^{m-1}\sum_{y=0}^{n-1}\left\| I_{\mathrm{w}}(x,y) - I(x,y)\right\|^2, \tag{3}$$

where m and n are the dimensions of an image, x and y are the image coordinates, $I_{\mathrm{w}}(x,y)$ is the watermarked image, and $I(x,y)$ is the cover work. The PSNR is often given in decibels. Values above 40 dB indicate low degradation, while values below 30 dB indicate low quality [2].

When the optimal radius is found the encoder uses it for the implementation of the watermark. Elements of the watermark matrix are calculated using the equation:

$$W(x_i, y_i) = v(j)\left(\frac{1}{9}\sum_{s=-1}^{1}\sum_{t=-1}^{1} M(x_i + s, y_i + t)\right), \tag{4}$$

where $W(x_i,y_i)$ are elements of the watermark matrix, $v(j)$ is the j-th element of the row-vector v; and $M(x_i,y_i)$ are the elements of the magnitude of the cover image.

Coordinates (x_i,y_i) are defined as:

$$x_i = (\frac{m}{2}+1) + \left\lfloor r_0 \cos(\frac{\mathrm{j}\cdot\pi}{l}) \right\rfloor, \tag{5}$$

$$y_i = (\frac{n}{2}+1) + \left\lfloor r_0 \sin(\frac{\mathrm{j}\cdot\pi}{l}) \right\rfloor. \tag{6}$$

Where m and n denote size of the matrix M, r_0 is implementation radius, l denotes the length of the row-vector, and $\lfloor\cdot\rfloor$ denotes a floor operator.

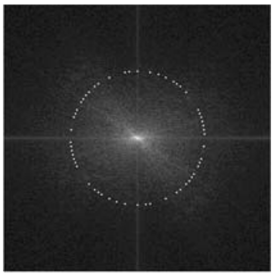

Figure 3 *Embedded watermark in the spectra of the Fourier domain (intensities of the watermark coefficients are exaggerated to be visible on the print).*
Slika 3. *Vodeni znak umetnut u spektar Fourierove domene (intenzitet koeficijenata vodenog znaka je uvećan kako bi bio vidljiv u tisku)*

The elements of the watermark are equally spaced around the center of the watermark matrix, and the watermark matrix is then embedded in the magnitude coefficients (spectra) of the cover work (Fig. 2) using the equation:

$$M_{\mathrm{w}}(x, y) = M(x, y) + \alpha \cdot W(x, y), \tag{7}$$

where x and y are image coordinates, M is the magnitude of the cover image, W is the watermark matrix, α is the implementation coefficient, and M_{w} is the magnitude of the watermarked image.

Finally, the watermarked magnitude coefficients $M_{\mathrm{w}}(x,y)$ (Fig. 3) are combined with unaltered phase coefficients $\varphi(x,y)$ and transformed back to the spatial domain. The result is the watermarked image I_{w}.

3.2 Decoding
Dekodiranje

A decoder makes a blind iterative search for the implemented watermark. Therefore, for detection, the original image is not required. The only requirement is the key used for the generation of the watermark. Block diagram of the decoder is shown in Fig. 4.

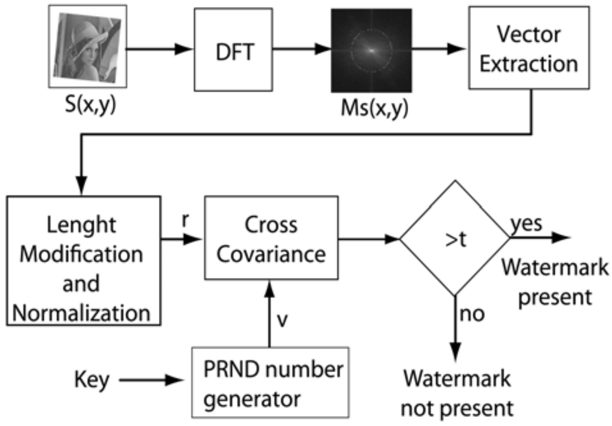

Figure 4 *Block diagram of the decoder*
Slika 4. *Blok dijagram dekodera*

To test for the existence of a watermark in an image, the image is resized to 512×512 pixels using bilinear interpolation. After scaling, the image is transformed to the Fourier domain. Then row-vectors are extracted from the magnitude coefficients of the image from radii $r_{\min}$ to $r_{\max}$. Each extracted vector is then resized to length l_{e} defined by equation:

$$l_{\mathrm{e}} = r_{\max} \cdot \pi. \tag{8}$$

The values are normalized to interval [0 1]. After normalization, cross covariance is calculated between the extracted vector r, and the row-vector v generated with a pseudo-random generator using the original key as a seed. The cross-covariance of two vectors is actually a cross-correlation of the vectors with removed mean value. It is defined as:

$$C_{rv}(m) = \begin{cases} \sum_{n=0}^{N-|m|-1} \left(r(n-m) - \bar{r}\right)\left(v_i^* - \bar{v}^*\right), & m \geq 0 \\ C_{rv}^*(-m), & m < 0 \end{cases}, \tag{9}$$

where, C_{rv} is the cross covariance of vectors r and v, $\overline{r}$ and $\overline{v}$ are mean values of vectors r and v respectively, and * denotes complex conjugation

The watermark detection is positive if the maximum value of cross-covariance exceeds a predefined detection value t.

4 Experiment
Eksperiment

The results were obtained by evaluation of the detection value (correlation) from dataset of 1000 images which went through the process of AM halftoning. The values of watermarked continuous images and unwatermarked images were used for comparison. Three different shapes of clustered dots were used (round, ellipse and line dot), with four different halftone frequencies (10, 13 15, 40, and 60 line/cm).

The robustness of the watermarking method depends on the strength of implementation. Therefore, to ensure the repeatability of the test, the implementation factor for each image was chosen to produce a watermarked image with the PSNR value around 40 dB. The obtained histogram of

PSNRs is shown in Fig. 5. This value was chosen to obtain watermarked images that are perceptually indistinguishable from original images. An example of watermark embedding is shown in Fig. 6.

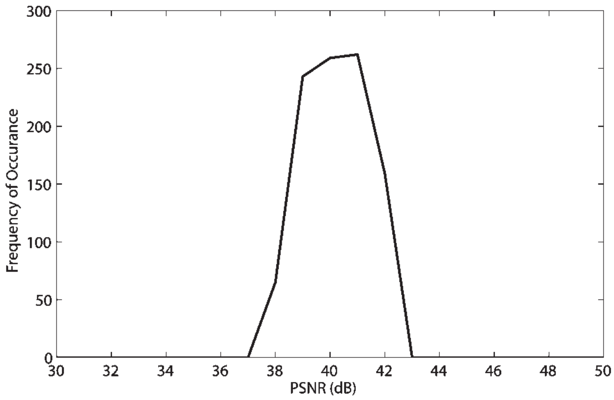

***Figure 5** Histogram of the PSNR values of watermarked images*
***Slika 5.** Histogram PSNR vrijednosti označenih slika*

***Figure 6** Example of watermark embedding; a) original image, and b) watermarked image (PSNR=41dB)*
***Slika 6.** Primjer umetanja vodenog znaka; a) originalna slika, i b) označena slika (PSNR=41dB)*

For the evaluation of robustness watermark detection probability, distribution of the detection values, and receiver operating characteristic (ROC) curves were used.

For the detection of a watermark in an image correlation of extracted vector *r* with the generated vector *v* has to exceed a value set as the threshold. Therefore, the probability of a detection of a watermark in an image depends on the threshold value *t*. The threshold has to be set low enough to enable the detector to detect a watermark in a watermarked image, even if the image goes through intentional or unintentional attacks which induce degradation (PS process, halftoning, compression, blurring, etc.). However, by decreasing the value of *t*, the probability of a false positive detection increases. The false positive detection occurs when the detector detects a watermark in an unwatermarked image which is, for practical watermarking methods, unacceptable.

The distribution of detection values shows the behavior of the watermarking method for individual images.

A receiver operating characteristic (ROC) curve is a graphical plot of the probability of true detection vs. the probability of false detection [16]. It provides a good tool for estimating the behavior of a detector for different type of degradations introduced to an image.

5 Results
Rezultati

5.1 Watermark detection probability
Vjerojatnost detekcije vodenog znaka

In Figures 7, 8 and 9 the watermark detection probability is shown for round, ellipse, and line halftones respectively. The detection probability after AM halftoning is compared with the detection probability prior to halftoning, and with the false positive probability ("Unwatermarked" in the legend of the figures).

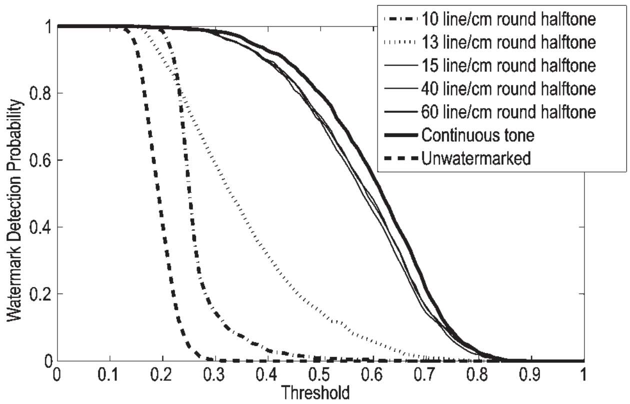

***Figure 7** Watermark detection probabilities for the different frequencies of a round halftone*
***Slika 7.** Vjerojatnost detekcije vodenog znaka za različite linijature točkastog rastera*

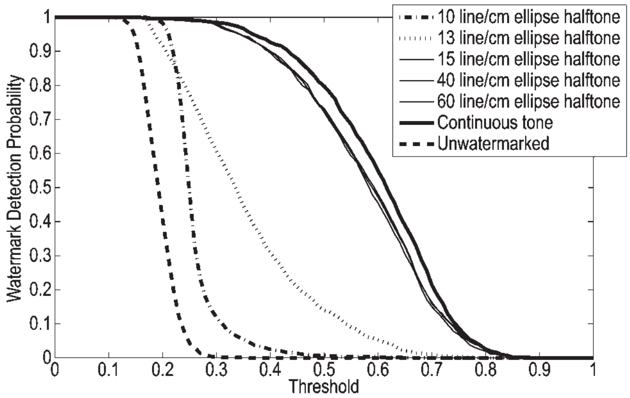

***Figure 8** Watermark detection probabilities for the different frequencies of an ellipse halftone*
***Slika 8.** Vjerojatnost detekcije vodenog znaka za različite linijature eliptičnog rastera*

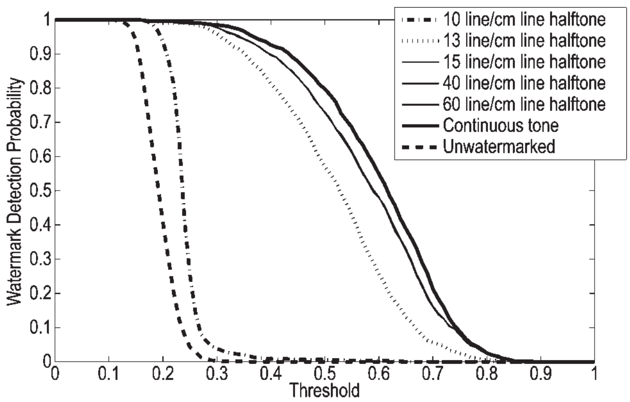

***Figure 9** Watermark detection probabilities for the different frequencies of a line halftone*
***Slika 9.** Vjerojatnost detekcije vodenog znaka za različite linijature linijskog rastera*

The results show that the detection rate depends more on frequency than on type of a halftone. Figures 7, 8, and 9 show that the line representing detection rate the frequency of 10 line/cm is too close to the line representing false positive rate. This means that it is possible for the detector to detect watermark (for t = 0,25) in most of the image processed with a halftone frequency of 10 line/cm; however, the false positive detection rate would be unacceptably high for any practical use.

For the frequency of 13 line/cm the detection probability is much better than for the frequency of 10 line/cm. Still, for round and ellipse halftones (Fig.-s 7, 8) this watermarking method is not robust enough for practical use. On the other hand, the watermarking method is robust to the line halftone of frequency of 13 line/cm (Fig. 9).

The detection rate for halftone images with frequencies higher than 13 line/cm show considerable robustness of the watermarking method. For frequencies higher than 15 line/cm the watermark detection probability changes very little, and is almost the same as the detection rate prior to halftoning.

5.2 Distribution of detection values
Distribucija detektiranih vrijednosti

Histograms of the detected correlation values for round, ellipse, and line halftones are shown in Figures 10, 11, and 12 respectively.

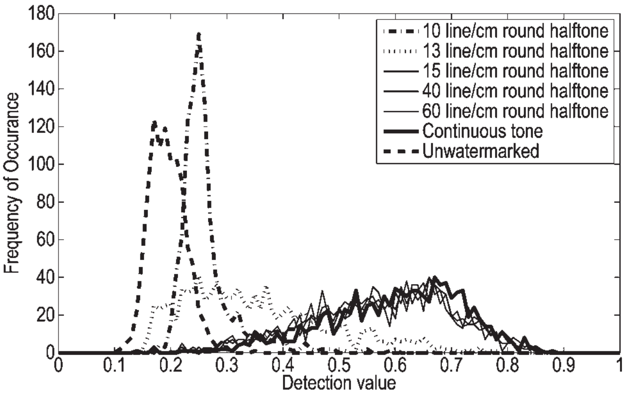

Figure 10 *Histogram of detection values for a round halftone*
Slika 10. *Histogram detektiranih vrijednosti za točkasti raster*

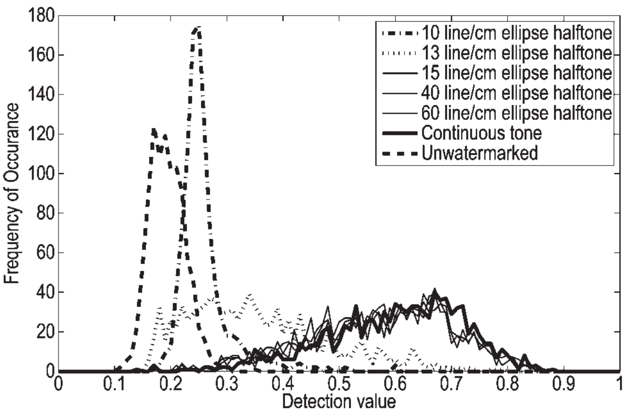

Figure 11 *Histogram of detection values for an ellipse halftone*
Slika 11. *Histogram detektiranih vrijednosti za eliptični raster*

For unwatermarked images mean detection value is 0,19 with standard deviation of 0,03. The reason that the mean detection value is not around zero is that the detector searches for the embedded watermark and returns the detection value which is actually the maximum correlation value of that search.

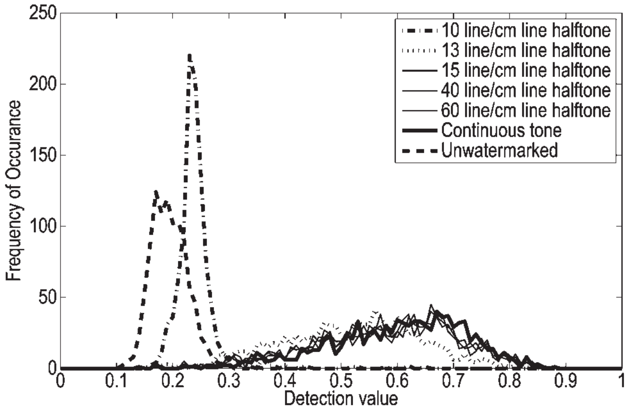

Figure 12 *Histogram of detection values for a line halftone*
Slika 12. *Histogram detektiranih vrijednosti za linijski raster*

For frequencies higher than 15 line/cm the distribution of detection values is similar to the case without halftoning. For a line halftone, however, even the frequency of 13 line/cm comes close to continuous tone result (Fig. 12).

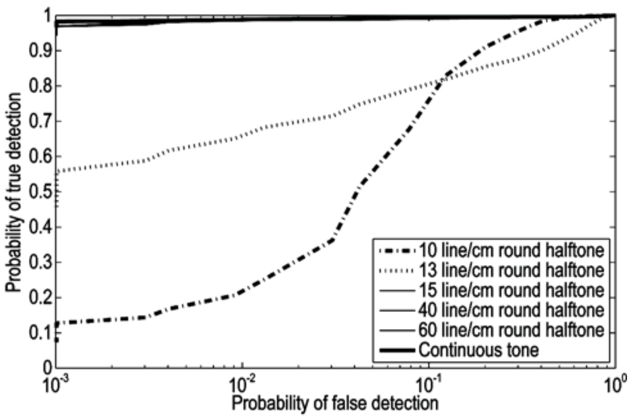

Figure 13 *ROC curve for a round halftone*
Slika 13. *ROC krivulja za točkasti raster*

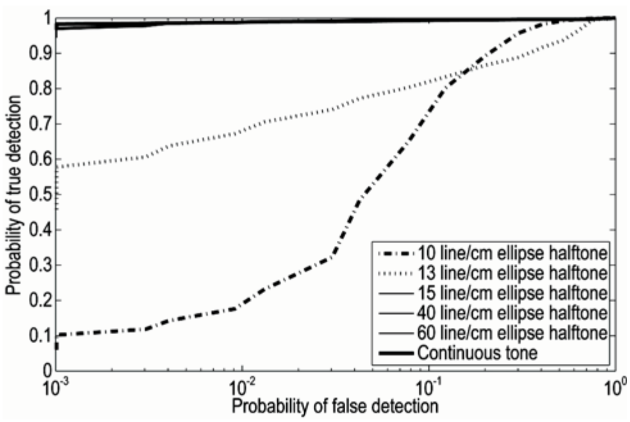

Figure 14 *ROC curve for an ellipse halftone*
Slika 14. *ROC krivulja za eliptični raster*

5.3 ROC curves
ROC krivulje

ROC curves for round, ellipse, and line halftones are shown in Figures 13, 14, and 15 respectively. ROC curve

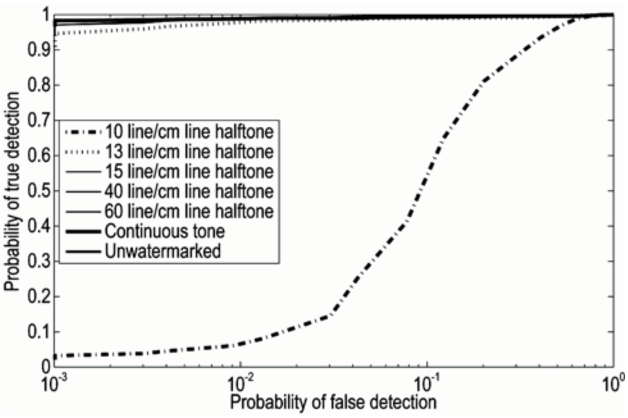

Figure 15 *ROC curve for a line halftone*
Slika 15. *ROC krivulja za linijski raster*

analysis confirms previous results. The type of a halftone is less important than the frequency. The difference is for a line halftone for which the watermarking method shows more robustness than round and ellipse halftones. However, this is the case for the frequency of 13 line/cm, while for lower frequencies the result is the same or worse than for round and ellipse halftones.

6 Conclusion
Zaključak

AM halftoning can induce irreversible degradation to a watermarked image, and consequently destroy the embedded watermark. This happened in case of frequencies lower than 15 line/cm. However, such low frequencies are not used in practical print production (with the exception of billboard printing).

It is concluded that detection rate of a DFT based watermarking method depends on the shape of the clustered dot much less than on the halftone frequency. Furthermore, this particular watermarking method is robust to halftone frequencies as low as 15 line/cm. For frequencies that are lower than 15 line/cm, the mean detection value is too low for practical usage.

Future work will focus on the influence of the AM halftoning combined with other possible distortions such as rotation, scaling, and cropping.

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