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DIGITAL IMAGE AUTHENTICATION USING IMAGE FILTERING TECHNIQUES

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Abstract. There is a digital snapshot taken by digital camera. Main problem is to decide if the image was deliberately changed or if it is an original. Current state of research is presented in this paper. Typical deliberate changes are shown. Some techniques to detect them are presented. The convolution filtering techniques and spectral filtering ones have been used to achieve our objective. Examples of the use of our techniques are also included.

Key words. digital image authentication, image processing, convolution filtering, spectral filtering

1. Introduction. Recently computers are penetrating practically all human life. Also digital cameras are becoming more usual. This process brings some new problems that should be solved.

There are many techniques how to distinguish original classical snapshots from falsified ones. Strictly different problem is doing so by digital snapshots. The Criminalistic Institute of the Police of Czech Republic started to fund a project, that attempts to solve this problem. They provided examples of falsified images. In some cases they provided also originals. Current state of research on this project is presented here.

2. Model Examples. There are many types of deliberate changes. Some of them are presented.

FIG. 2.1. *auto2.jpg and auto1.jpg*

The picture auto2.jpg (blue on the figure 2.1) is an original picture. Auto1.jpg (red on the figure 2.1) is falsified picture. Color and the plate of the car were changed. Original resolution of both these pictures was 640×480 points.

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FIG. 2.2. *cislo2.jpg and cislo1.jpg*

The picture cislo2.jpg (left on the figure 2.2) is a digital snapshot of falsified car motor number. Cislo1.jpg (right on the figure 2.2) was made from cislo2.jpg by a deliberate change - The position of two numbers has changed. Original resolution of both these pictures was 671×444 points.

FIG. 2.3. *mont0.jpg - montage of the worst quality*

We also investigate some montages. We have some examples with an airplane in clouds. The airplane was taken from another digital snapshot. These examples differs in quality. We present here mont0.jpg on the figure 2.3 - the montage of the worst quality, we have, and mont2.jpg on the figure 2.4 - the montage of the best quality, we have. Original resolution of both these pictures was 1600×1200 points.

FIG. 2.4. *mont2.jpg - montage of the best quality*

FIG. 2.5. *tichy1.jpg*

Tichy1.jpg, digital picture on the figure 2.5 is also montage. The person is fictitious. It was composed from three another persons. Original resolution of this picture was 412×464 points.

3. Detection Principles. All our detection attempts are based on a simple prediction that **no deliberate changes are made absolutely perfectly**. It means that every deliberate manipulation makes some marks in digital image, that could be detected. Although, possibly there could be perfectly made changes, but our research is not interested in the questions of their realizability and probability of their occurrence.

Digital images manipulations for the purpose of the change of the information contained in the picture can be made by various ways. For this reason we can not expect that there exists only one universal method for the detection of such manipulations, but we must investigate several different approaches ([6]). Recently we consider the most perspective approaches, that seek in images hidden discontinuities, these could be signs of former manipulations. This paper presents a small part of this kind of approaches.

We are not able to exactly define the term "discontinuity". Intuitively we can understand to it like a "dishomogenity" or "exceptionality" in the progress of brightness function. If some part of digital picture was replaced by something else, we can expect, discontinuities appear on the border of such a part. But by the analysis of the image we must distinguish between our "hidden discontinuities" and "natural discontinuities" like edges, that makes our task much more difficult ([6]).

In this paper we present methods based on differential operators in the image area and methods based on the frequential analysis of the image.

3.1. Differential Operators. Differential operators have been a classical task for discontinuity detection for many years (found in [6]). Some of them are also known as edge detectors. These operators can be categorized into two major groups according the order of derivatives they use.

The first-order operators detect the discontinuities as the points in which the image function has big values of the first-order derivatives. They differ from each other in how the derivatives are numerically estimated. In other words, they use different convolution masks. The discrete convolution is computed by the following formula:

$$h_{i,j} = \sum_{k=d}^{n} \sum_{l=d}^{n} g_{k,l} f_{i+k,j+l},$$

where $d = -(s-1)$ div 2 and $n = s$ div 2, g is a convolution mask of the size $s \times s$, f is the image function. The most common masks are Roberts' mask

$$\begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix},$$

Sobel mask

$$\begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix},$$

and Prewitt mask

$$\begin{pmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{pmatrix},$$

among others. More details on the implemetation and many other examples can be found in [1], [4], [5].

Second-order operators calculate the convolution of the image with the function $\triangle G$, where $\triangle$ denotes numerical Laplacian and G stands for 2-D Gaussian. Then so-called zero-crossing points indicate the presence of discontinuities. Zero-crossing points are the points in the neighborhood of which $(\triangle G) * f$ changes its values from positive to negative or vice versa. However, because of discretization of the image, the zero crossing points cannot be found by solving the equation $(\triangle G) * f = 0$. They must be localized by matching of appropriate templates that characterize all possible distributions of positive and negative values in the neighborhood.

This technique is robust to noise thanks to the Gaussian function. Moreover, changing its standard deviation we can control the smoothing effect according to the signal-noise ratio of the original image.

The above described idea came from Marr and Hildreth [3] and is currently considered as the best general-purpose edge detector. It significantly outperforms the first-order operators, particularly if noise is present. On the other hand, it is much more computationally demanding.

It seems, especially Marr edge detectors $(\triangle G)$ can probably detect "false edges" i.e. hidden discontinuities (see Section 4). For this reason we should present here how these convolution masks looks. Marr edge detector of the 5×5 order:

$$\begin{pmatrix} 0 & 3 & 6 & 3 & 0 \\ 3 & 15 & 0 & 15 & 3 \\ 6 & 0 & -108 & 0 & 6 \\ 3 & 15 & 0 & 15 & 3 \\ 0 & 3 & 6 & 3 & 0 \end{pmatrix}$$

Marr edge detector of the 11×11 order:

$$\begin{pmatrix} 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 2 & 2 & 2 & 2 & 2 & 1 & 1 & 0 \\ 1 & 1 & 2 & 2 & 1 & 1 & 1 & 2 & 2 & 1 & 1 \\ 1 & 2 & 2 & 0 & -2 & -4 & -2 & 0 & 2 & 2 & 1 \\ 1 & 2 & 1 & -2 & -8 & -10 & -8 & -2 & 1 & 2 & 1 \\ 1 & 2 & 1 & -4 & -10 & -12 & -10 & -4 & 1 & 2 & 1 \\ 1 & 2 & 1 & -2 & -8 & -10 & -8 & -2 & 1 & 2 & 1 \\ 1 & 2 & 2 & 0 & -2 & -4 & -2 & 0 & 2 & 2 & 1 \\ 1 & 1 & 2 & 2 & 1 & 1 & 1 & 2 & 2 & 1 & 1 \\ 0 & 1 & 1 & 2 & 2 & 2 & 2 & 2 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \end{pmatrix}$$

We can see that these convolution masks are symmetric both horizontally and vertically. This is because of the symmetry of Gaussian function. For this reason and because its size, we present here only upper left quarter of Marr edge detector of the 31×31 order:

0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2
0	0	0	0	0	0	0	0	1	1	1	2	2	2	2	3
0	0	0	0	0	0	1	1	1	2	2	3	4	4	4	5
0	0	0	0	0	1	1	2	2	3	4	5	6	7	7	7
0	0	0	0	1	1	2	3	4	5	7	8	9	10	10	11
0	0	0	1	1	2	3	4	6	8	10	11	12	13	14	14
0	0	0	1	2	3	4	6	9	11	12	14	14	15	15	15
0	0	1	1	2	4	6	9	11	13	14	15	15	14	13	13
0	0	1	2	3	5	8	11	13	15	15	14	11	8	5	4
0	1	1	2	4	7	10	12	14	15	13	9	2	−4	−9	−11
0	1	2	3	5	8	11	14	15	14	9	0	−11	−22	−31	−34
0	1	2	4	6	9	12	14	15	11	2	−11	−28	−44	−56	−60
1	1	2	4	7	10	13	15	14	8	−4	−22	−44	−65	−80	−86
1	1	2	4	7	10	14	15	13	5	−9	−31	−56	−80	−98	−104
1	2	3	5	7	11	14	15	13	4	−11	−34	−60	−86	−104	−112

There are also Marr detectors of higher and smaller order, but they all can not be presented here.

3.2. Spectral Approaches. Spectral analysis is a classical powerful tool used in image processing. We just compute discrete Fourier transform with the following formula:

$$F_{k,l} = \frac{1}{\sqrt{MN}} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f_{m,n} e^{-2\pi i \left(\frac{km}{M} + \frac{ln}{N}\right)},$$

where f is a brightness function of the image of the size $M \times N$. $F_{k,l}$ are complex numbers. Every this number can be written as $F_{k,l} = A_{k,l} e^{i\varphi_{k,l}}$, $\varphi_{k,l}$ is a phase and $A_{k,l}$ is an amplitude. Local maximums of amplitude at higher frequencies may be signs of periodicity in the picture. These can be sign of some types of manipulations like cloning. Because the value of an amplitude at low frequencies is usually many times higher, than the value at high frequencies, at higher frequencies we usually search for maximums of the natural logarithm of the amplitude - maximums of the logarithmic spectrum.

4. Experiments and Results. We have made some experiments and we think we will be able to detect some ways of falsifications. Hopeful could be using of convolution filtering, Fourier transform and filtering in the spectral area. Experiments were made in system ZODOP, that was developed in the department of image processing of Institute of the Information Theory and Automation of Czech Academy of Sciences in Prague. System ZODOP has implemented big amount of tools for filtering both in the picture and in the spectral area. All computations were made on Pentium III 500MHz, 256MB RAM, Windows NT 4.0 Workstation.

All of our testing images are color ones. For this reason, the convolution filtering was applied on each color channel separately. Fourier transform was always computed from the brightness function after the picture was transformed into greyscale image.

Marr operators could be useful on the images with the change of color. On the figure 4.1 we can see images from the figure 2.1 after convolution filtering with Marr filter of the size 31×31. We can see that the original image is relatively grey, but the

FIG. 4.1. *auto2.jpg and auto1.jpg after application of Marr filter* 31×31.

falsified one is colorful. This is caused by "hidden discontinuities" that occurred in the picture after the original color was replaced. It can be seen, that the falsified car plate is not detected by this way. Computation took about half a minute.

On the figure 4.2 we can see logarithmic spectra of the images from figure 2.2 Frequencies that occurred after the periodization of the original image are marked.

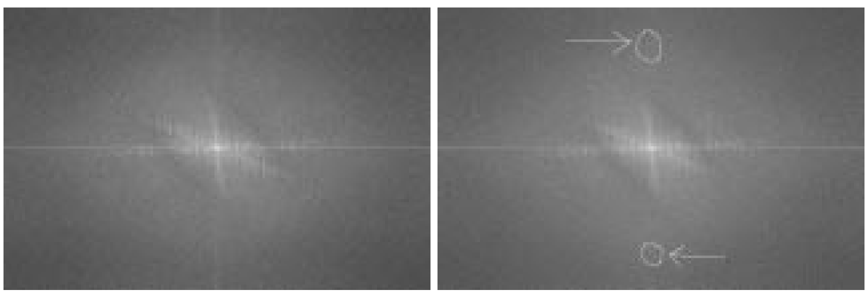

FIG. 4.2. *logarithmic spectra of cislo2.jpg and cislo1.jpg*

The periodization was made by the change of the rank of numbers. Computations took about 5 sec. Because of the bad visibility of difference on the figure 4.2, on the

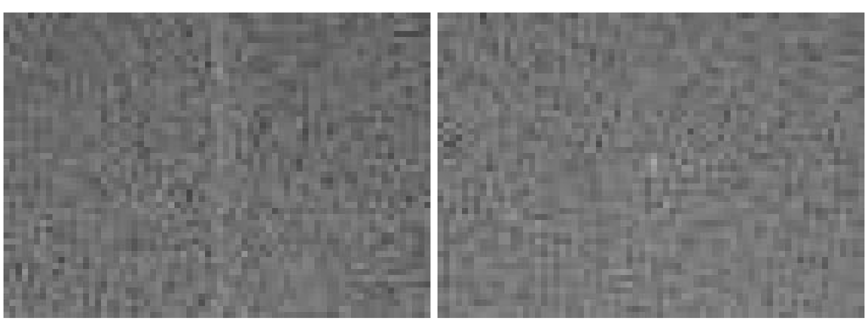

FIG. 4.3. *detail of the part of logarithmic spectra of cislo2.jpg and cislo1.jpg*

figure 4.3 is a detail of both images at upper part, where new frequencies occurred. We can see a local maximum (light) at the center of the right picture at this figure.

FIG. 4.4. *mont0.jpg after the convolution with Sobel mask*

Sobel convolution mask was used on all montages, we have, with partial success. The results gained from mont0.jpg (on the figure 2.3) and mont2.jpg (on the figure 2.4) could be seen on the figures 4.4 and 4.5. On the relatively primitive montage mont0.jpg we can see a pairs of parallel edges very close each to other. The most perfectly made montage on the picture mont2.jpg was a bit smoothed on the boundaries. For this reason Sobel detector detects here relatively thick edges, but if we did not know, this has been a montage, we think, we would make no association.

Although, the image Tichy1.jpg (figure 2.5) is falsified, our experiments did not find any signs of this falsification.

5. Conclusions. In the last section we have presented some ways, how some deliberate manipulations with digital images may be detected. But number of testing images is very limited. So it is very difficult to decide, if these results are really only signs of manipulations and not just specialities of the current picture. We should have many times larger number of testing images to make some adequate conclusion.

Digital image authentication is a completely new research topic ([2]). Only current state of research at this area of digital image processing has been presented at this paper.

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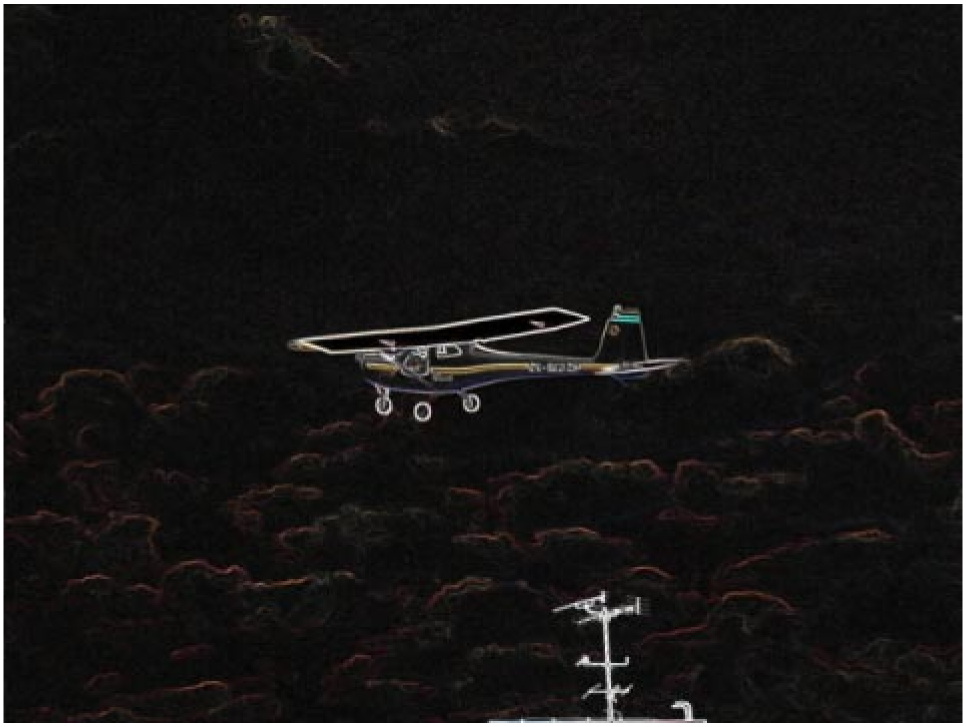

FIG. 4.5. *mont2.jpg after the convolution with Sobel mask*

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