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Digital inpainting with applications to forensic image processing

Voronin V.V.[(a)], Marchuk V.I.[(a)], Semenishchev E.A.[(a)], Makov S.V.[(a)], Creutzburg R.[(b)]; (a) Don State Technical university, Dept. of Radio-Electronics Systems, Gagarina 1, Rostov on Don, Russian Federation; (b) Dept. of Informatics and Media, Fachhochschule Brandenburg, Brandenburg, Germany

Abstract

With the development of multimedia processing and applications, multiple types of media security and forensic have been broadly taken into consideration. The media data includes audio, video, graphic, image and etc. There are three main applications of the forensic image processing: hiding data, tampering detection and recovering of the digital information. Some artifacts and lost details on the image or video could lead to an erroneous interpretation. The objective of this paper is to ensure the production of quality forensic imagery using digital inpainting. Inpanting in images and videos aims at filling gaps (holes) occur due to instrumentation error, losses of image data during transmission. The holes may correspond to missing parts or removed objects from the scenes (logos, text, etc.). This paper includes brief descriptions of advantages, disadvantages, and potential of inpainting with applications to the forensic image processing. We present an image inpainting method based on the texture and structure propagation. It is shown that this approach allows restoring a fingerprint, missing blocks and removing a text from the scenes. Several examples considered in this paper show the effectiveness of the proposed approach for large objects removal as well as recovery of small regions on several test images and videos.

Introduction

Nowadays all type of the communication techniques has been done with the help of the multimedia data such as image and video. With the development of multimedia processing and applications, multiple types of media security have been broadly taken into consideration. The type of media includes audio, video, text, graphic, image and web pages. Through the multimedia editing tools one can easily change the content of data which lead to lose the authenticity of the information. Multimedia forensic including image and video forensic is still a young field in this science. Processed images and videos are used for many purposes by the forensic science community. They can yield information not readily apparent in the original image, which can assist an expert in drawing a conclusion that might not otherwise be reached. Some artifacts on the image or the loss detail could lead to an erroneous interpretation. There are main applications of forensic image processing: hiding, evidence and recovering of the digital information. Image reconstruction or image inpainting is an important topic in image processing, which can be applied in many areas, from the automatic restoration of damaged photographs to removal of unwanted objects in images. Popular terms used to denote inpainting algorithms are also "image completion" and "image fill-in". The main goal of inpainting is to restore missing («empty») pixels using information from outside of the damaged domain. The notion of digital inpainting was first introduced by Bertalmio and etc. in [1]. Smart digital inpainting models, techniques, and algorithms have broad applications in image interpolation, photo restoration, zooming and super-resolution, primal-sketch based perceptual image compression and coding, and the error concealment of (wireless) image transmission, etc. Some objects which are not expected in the image, such as unconscious scratch, signature and so on can be effectively reduced by image restoration techniques. Inpanting in images and videos aims at filling gaps occur due to instrumentation error, losses of image data during transmission; such area involve reconstruction in satellite image referred as gapped area in satellite images. Video inpainting refers to the field of computer vision which aims at filling-in holes in a video sequence using spatial and temporal information from neighboring regions. The holes may correspond to missing parts or removed objects from the scenes (logos, text, etc.). Video inpainting techniques find a wide range of applications in video processing where an unknown region in the scene has to be estimated in a way providing visually coherent results. For instance, error/loss concealment which is a post-processing technique usually performed at the decoder side to recover missing blocks of streams. The main objective of video inpainting approaches is to complete the hole in a way which would be as visually plausible as possible both in space and time. The image restoration technology has become a new active research direction in the field of forensic image processing, the purpose is to detect and resolve the parts of image damaged, and automatically recover the full fingerprint image based on effective information around the image using reconstruction algorithm [2].

The objective of this paper is to ensure the production of quality forensic imagery. This document includes brief descriptions of advantages, disadvantages, and potential of each major process. In this paper an image inpainting approach based on the texture and structure propagation is presented.

The outline of this paper is as follows: the brief description of digital inpainting methods with applications to the forensic image processing is in Section 2. Section 3 describes the proposed method. Section 4 demonstrates the experimental study in detail, followed by the Conclusion section.

Previous work

Multimedia forensic descends from the classical forensic science that studies the use of scientist methods for gaining probative facts from physical or digital evidences. Digital image forensics has a very precise role among multimedia security disciplines. The task of multimedia forensic tools is to expose the traces left in multimedia content by each step of its life, by exploiting existing knowledge on digital imaging and in multimedia security research. Images, unlike text, represent an effective and natural communication media for humans, due to their immediacy and the easy way to understand the image content. With the rapid diffusion of inexpensive and easy to use devices that enable the acquisition of visual data, almost everybody has today the possibility of recording, storing, and sharing a large amount of digital images. So we need some methods that allow the

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reconstruction of the history of a digital image in order to verify its truthfulness and assess its quality.

There are three main applications of the forensic image processing: hiding data, tampering detection and recovering of the digital information. By image editing, any processing applied to the digital media is meant. There are many different reasons for modifying an image: the objective could be, for example, to improve its quality or to change its semantic content. In this paper we consider the problem of restoration of images, because some artifacts and lost details on the image or video could lead to an erroneous interpretation.

Several methods have been reported for the restoration of fingerprints from different forensic applications [3]. Hong [4] introduced the method of gabor filtering for fingerprint images; Miao [5] proposed the method of minutiae extraction by tracing the ridges on gray image; Jianxin [6] described the effective method for fingerprint enhancement. Performance of gabor method and diffusion filtering method are comparatively better than others among above methods. The method expressed in [7] combined the gabor filtering and dilatation method. The method described in [8] based on fast Fourier transform. All these methods consider the ridges and valleys enhancement only and not considering scars and scratches removable.

Video is usually acquired in interlaced format, where each image frame is composed of two image fields, each field holding same parity lines. But many display devices require progressive video as input, and also many video processing tasks perform better on progressive material than on interlaced video. There are a vast number of techniques in this field, techniques which can be based on intra-frame reconstruction methods, inter-frame reconstruction methods or a combination of both [9]. There is an important selection between speed and quality of these algorithms. The algorithms that introduce less visual artifacts require computationally intensive procedure Motion Compensation. On the other hand, the algorithms based on a directional spatial and temporal interpolators for each missing pixel. Directional interpolators have varied problems such as being sensitive to noise, being only able to detect a limited number of orientations or having problems to reconstruct periodic structures [10]. In order to transmit video streams on band width limited wireless channels, video compression technologies like H.264 are needed not only to reduce bit stream size but also to retain the video quality. Unfortunately, video suffers from bit errors that are caused by path loss, long-term and short term fading effects. Temporal error concealment (EC) is an useful video coding technique to recover the errors in video transmission.

Inpainting or image reconstruction uses to restore missing («empty») pixels using information from outside of the damaged domain. This is good tools for above applications to forensic image processing. Inpainting methods generally divided into two categories: techniques originally developed for images and applied frame-wise to videos [11], and algorithms specifically proposed to video sequences. The methods from second group use spatial and temporal correlation between frames. Digital inpainting serves a wide range of applications, such as removing text and logos from still images or videos, reconstructing scans of deteriorated images by removing scratches or stains, or creating artistic effects. This problem is also especially valuable in computer vision systems for image editing and recovery of missing blocks in image coding.

Most of image reconstruction methods can be classified into the following groups based on geometry [1,11], statistics [12,13], sparsity [14-16], exemplars [17-20] and edges [21] methods. The following models of images are used in image inpainting: bounded variation image model, local inpainting, total variation models, curvature-driven diffusions model and Markov random fields model. All these models are used in the methods which compute an optimal solution based on partial differential equations (PDE). In these methods, also called as diffusion-based, missing pixels are restored by a smooth propagation of information from the neighborhood of the holes by a diffusion process. These techniques often introduce a blur in sharp transitions in image and image contours, and need a priori information to select parameters of the method. They are suitable for removal of scratches and small defects on the structure of images, but often fail to restore the texture image and curved contours.

A second group of image inpainting methods uses the frequency domain processing and sparse representation model. It should be noted that these methods often tend to blur textures and structures in a recovery of large areas of missing pixels. These iterative methods are also highly computationally expensive.

A third group of image inpainting methods is based on non-parametric sampling model and texture synthesis. Criminisi et al. [17] have proposed a patch-based method based on searching for similar patches and coping them from the true image. These methods are limited to inpaint linear structures and often fail to recover curvy boundary edges.

Recently there have been developed various image inpainting methods based on combinational structure and texture propagation. These techniques are more suitable for structure and texture reconstruction, but requires significant computational time to inpaint large missing regions. The main drawbacks of the known methods come from the fact that the most of them are unable to recover the curved edges and applicable only for scratches and small defects removal. It should be also noted that these methods often blur image in the recovery of large areas with missing pixels. Most of these methods are computationally very demanding and inappropriate for implementation on modern mobile platforms.

The proposed method

In this work we use geometric image model [22] (fig.1). A discrete image defined on a $I \times J$ rectangular grid is denote $\{Y_{i,j}\}(i=\overline{1,I}, j=\overline{1,J})$. When each element $Y_{i,j}$ is a random variable, $\{Y_{i,j}\}$ is called a discrete random field. A simplified mathematical model of the original image can be represented as follows: $Y_{i,j} = (1 - M_{i,j}) \cdot S_{i,j} + M_{i,j} \cdot R_{i,j}$, $i=\overline{1,I}$, $j=\overline{1,J}$, where $S_{i,j}$ are the true image pixels; $M = \lfloor M_{i,j} \rfloor$ is a binary mask of the distorted values of pixels (1-corresponds to the missing pixels, 0-corresponds to the true pixels); $R_{i,j}$ are missing pixels; I is the number of rows, and J is the number of columns.

In [23] we have proposed the algorithm which allows restoring both large and small regions with missing pixel values with a high accuracy. This is achieved by a separate reconstruction of the structure and texture regions in images. We introduce a novel algorithm for automatic image inpainting based on 2D autoregressive texture model and structure curve construction (fig. 2). In this case any image can be divided into several areas such as texture regions and edges on the local geometric features and different spatial configuration.

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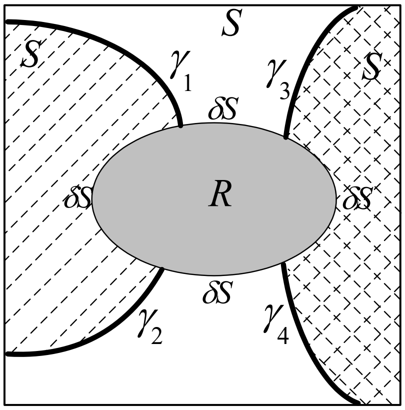

Figure 1. The image model

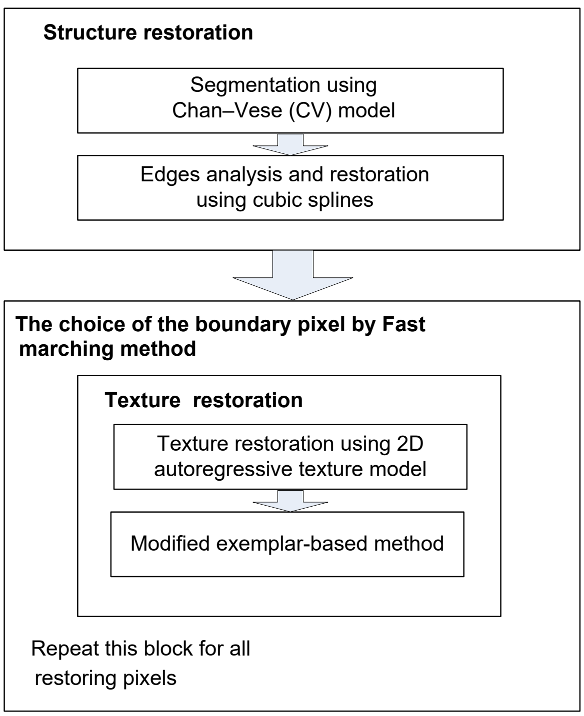

Figure 2. The proposed inpainting algorithm

One of the important step in proposed image inpainting algorithm is segmentation. In this paper we used a method that was developed by Chan and Vese in [24]. The Chan–Vese (CV) model is an alternative solution to the Mumford–Shah problem which solves the minimization of by minimizing the following energy functional:

$$E^{CV}(c_1,c_2,C)=\mu\cdot Length(C)+\lambda_1\cdot\int\limits_{inside(C)}\left|u_0(x,y)-c_1\right|^2dxdy+$$
$$+\lambda_2\cdot\int\limits_{outside(C)}\left|u_0(x,y)-c_2\right|^2dxdy \quad ,(1)$$

where μ, λ_1 and λ_2 are positive constant, usually fixing $\lambda_1=\lambda_2=1$, c_1 and c_2 are the intensity averages of u_0 inside C and outside C, respectively.

In Figure 3 examples of image segmentation using CV methods for different images are given.

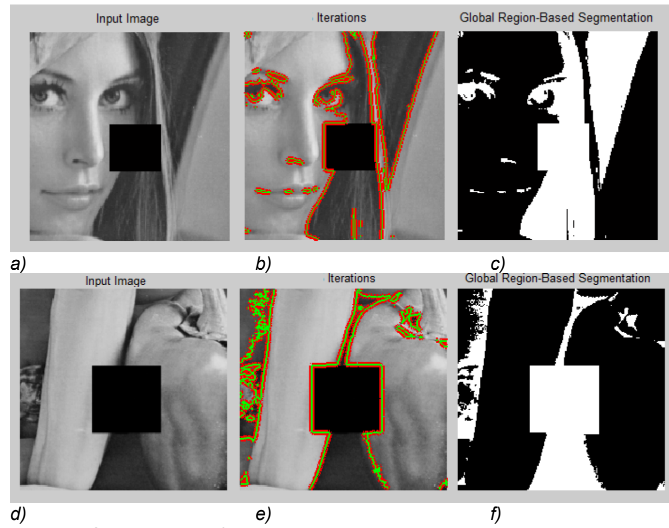

Figure 3. Segmentation of the test images

The first step is finding a correspondence between the boundaries that are crossing regions with missing pixels $R_{i,j}$. In Fig. 3a an example of segmenting Θ into three clusters (Θ_1 - the first cluster, Θ_3 - the second cluster, Θ_2 и Θ_4 - the third cluster) is shown. The pixels around the damaged image regions are clustered using boundaries, which allow to define the correspondence between the pixels from different patches.

For the cubic spline interpolation of each of the pairs of parts of the curves the concepts of parametric and geometric continuity are used. A matrix form of parametric equations describing the elementary cubic Hermite curve is given below:

$$\mathbf{B}(t)=\mathbf{G}\cdot\mathbf{M}\cdot\mathbf{T},\quad 0\le t\le 1,$$

$$\mathbf{G}=(P_k\ \ P_l\ \ \mathbf{Q}_k\ \ \mathbf{Q}_l)=\begin{pmatrix}x_k & x_l & u_k & u_l\\ y_k & y_l & v_k & v_l\end{pmatrix},\quad \mathbf{B}=\begin{pmatrix}x(t)\\ y(t)\end{pmatrix},$$

$$\mathbf{M}=\begin{pmatrix}1 & 0 & -3 & 2\\ 0 & 0 & 3 & -2\\ 0 & 1 & -2 & 1\\ 0 & 0 & -1 & 1\end{pmatrix},\quad \mathbf{T}=\begin{pmatrix}t^0\\ t^1\\ t^2\\ t^3\end{pmatrix}.$$

where $\mathbf{M}$ is a basis matrix of the cubic Hermite curve, $\mathbf{G}$ is a geometric matrix.

For a recovery procedure of edges on the basis of spline interpolation, see in more details [23].

The Fast Marching method is used in order to select a restored pixel in the area R, based on the solution of Eikonal equation

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$|\nabla T| = 1$ in the R and $T = 0$ on the border δS, where the solution of the equation T is the distance map of ψ_p pixels to the boundary δS [25].

The texture restoration algorithm is a modification of the example-based inpainting method proposed by Criminisi et al. [17]. The modification use autoregressive (AR) model for prediction lost pixels in the missing region before searching similar patch.

We represent a patch as 2D Random field [28]:

$$\hat{\Psi}_p = \sum\nolimits_{m\in s(o,p]} \phi_m \cdot X_{s-m} + \sum\nolimits_{n\in s(o,q]} \vartheta_n \cdot \eta_{s-n} + \eta_s , \quad (2)$$

where $(\phi_m)_{m\in s(o,p]}$ and $(\vartheta_n)_{n\in s(o,q]}$ denotes, respectively the autoregressive and moving average parameters with $\phi_0 = \vartheta_0 = 1$, and η_s denotes a sequence of distributed centered random variables with variance σ^2.

For finite order AR model the parameters can be estimated by using a 2D extension of the Yule-Walker equations.

After a texture restoration using 2D autoregressive texture model the exemplar-based method are carried out for every $\hat{\Psi}_p$. On the true image S we find patch ψ_q, for which the Euclidean distance is minimal $D_E(\hat{\Psi}_p, \Psi_q) = \sqrt{\sum(\hat{\Psi}_p - \Psi_q)^2} \to \min$. The pixels in a missing area R is restored by copying the corresponding pixels of the block Ψ_q found within the restored boundaries.

The proposed algorithm of texture restoration implemented using the following steps (Fig. 4).

Pseudo-code for texture restoration:

- $\psi_p = getHighestPriorityPatch(\delta S);$
- $\hat{\psi}_p = 2ARModelPatch(\psi_p);$
- $While\ (\psi_p\ exist):$

$\psi_{Pcand} = Search(\hat{\psi}_P);$
$(\psi_{q_1} ... \psi_{q_n}) = getCandidates(\psi_{Pcand});$
$\psi_q = getMatch(\hat{\psi}_P, (\psi_{q_1} ... \psi_{q_n}));$
$copy\,(\psi_q, \hat{\psi}_P);$
$constraintPriority\,(\psi_P);$
$updateConfidence(\psi_P).$

Repeat the above procedure for each restoring pixels.

Figure 4. Pseudocode for the proposed algorithm of texture restoration

Experimental results

The effectiveness of the presented scheme is verified on the test images with missing pixels. In Figures 5 and 6 examples of fingerprint restoration (a - the original image with a missing pixels, b – the mask of missing pixels, c - the image reconstructed by the Adobe Photoshop CS5 [26], d - the image reconstructed by the proposed method) are shown. We show comparison with algorithm in Adobe Photoshop CS5. The results show that the proposed method can more correctly restore the structure regions.

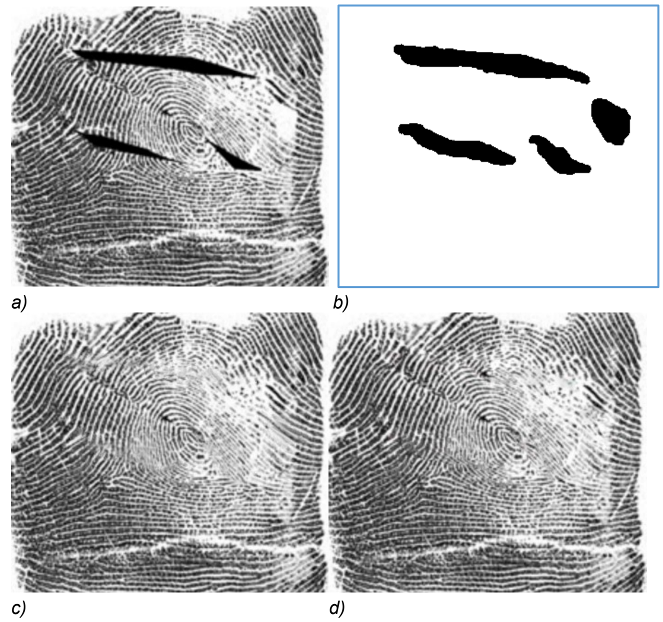

Figure 5. Examples of image restoration

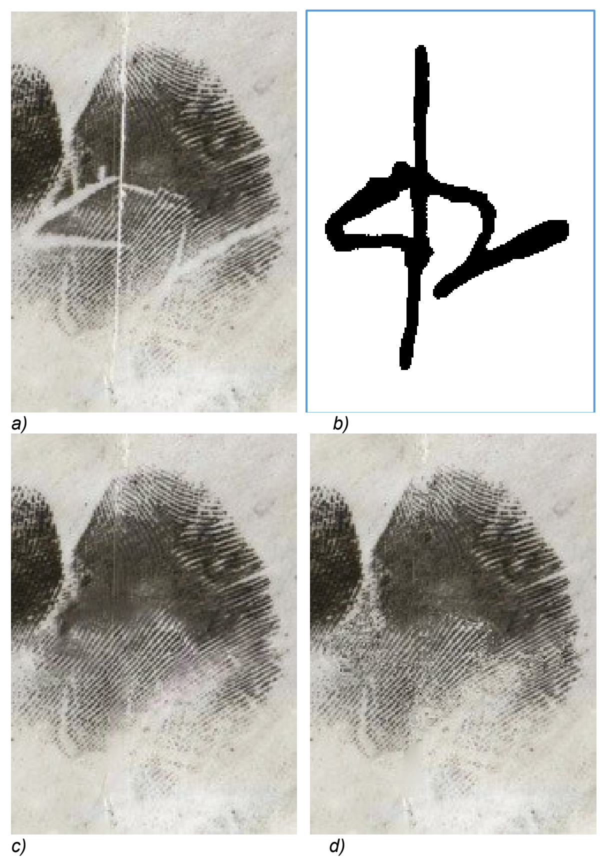

Figure 6. Examples of image restoration

The error concealment examples present in Figures 7 and 8. In this example, practically the entire missing region can be completed by proposed method better then result of the image reconstructed by

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the Adobe Photoshop CS5. The boundary pixel values of the house and wood of the images are correctly restored using the proposed method. It's also worth noting that the proposed method have some incorrect restoration of image and smear the texture and structure during the restoration of large areas of the missing pixels. Note what the Photoshop result have the blurring problem

The results on figure 9 shows example of logo and text remove. The region for removing is large and there are same artifacts which contain incorrectly synthesized structure at the lines on road.

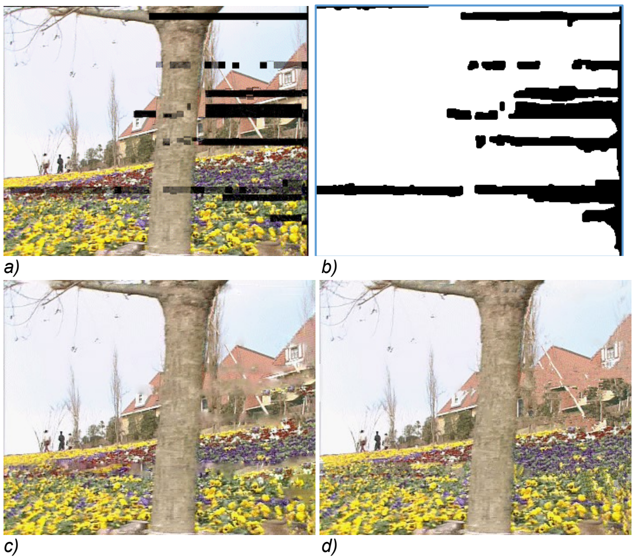

Figure 7. Examples of image restoration

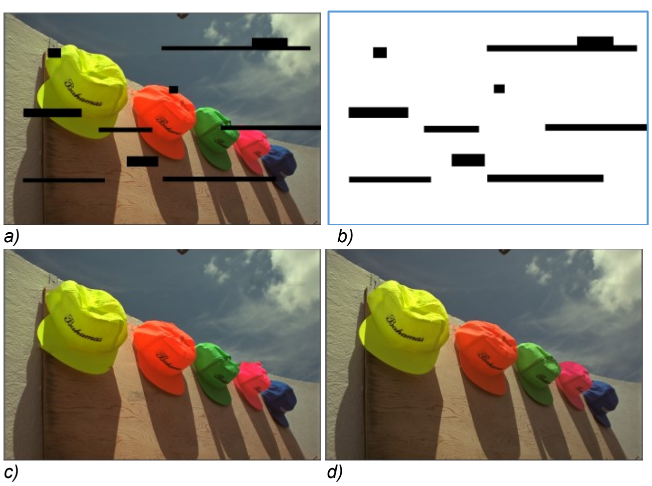

Figure 8. Examples of image restoration

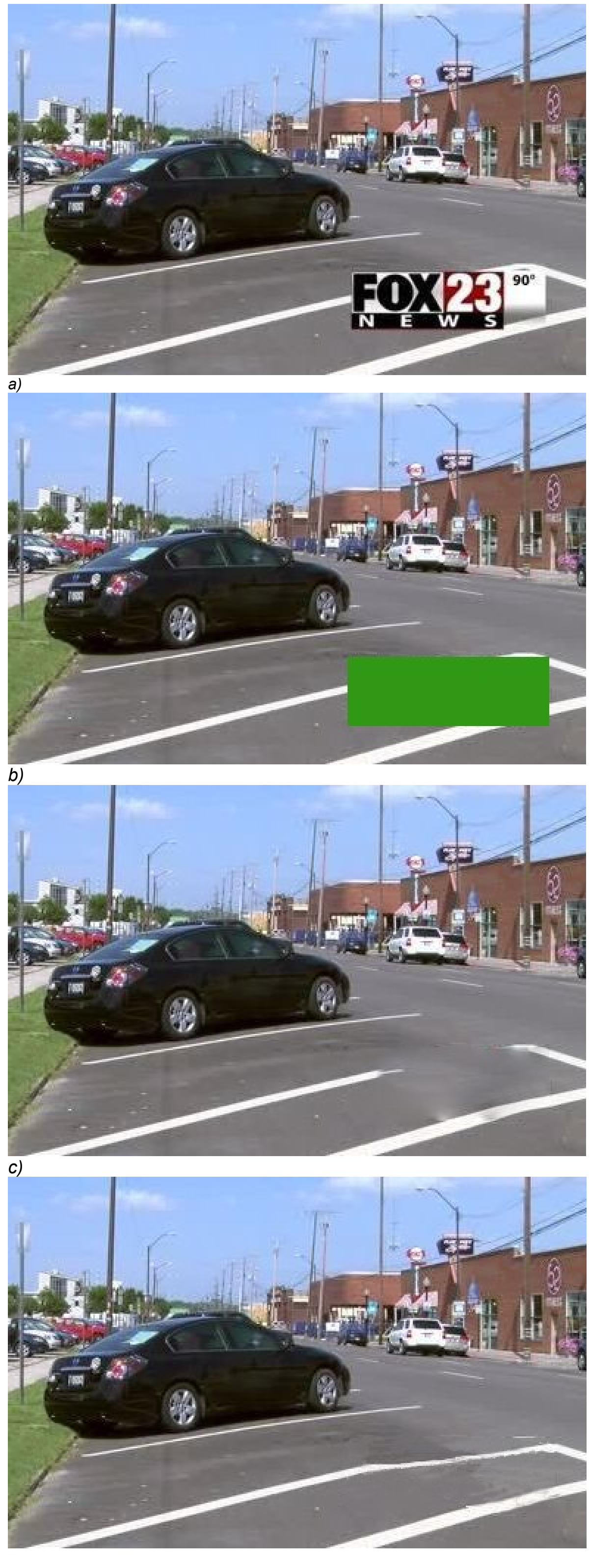

Figure 9. Examples of image restoration

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Conclusion

This paper includes brief descriptions of advantages, disadvantages, and potential of the forensic image processing. The image inpainting approach based on the texture and structure propagation is presented. It is shown that this approach allows to restore the curved edges and provide more flexibility for curve design in damaged image by interpolating the boundaries of objects by cubic splines.

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Author Biography

Viacheslav Voronin was born in Rostov (Russian Federation) in 1985. He received his BS in radio engineering from the South-Russian State University of Economics and Service (2006), his MS in radio engineering from the South-Russian State University of Economics and Service (2008) and his PhD in technics from Southern Federal University (2009). Voronin V. is member of Program Committee of conference SPIE. His research interests include image processing, inpainting and computer vision.

Vladimir Marchuk was born in 1951. Marchuk Vladimir received the Ph.D. degree in technics from Southern Federal University (Russian Federation) in 2006. Since 2006, he has been a Professor. His research interests are in the areas of applied statistical mathematics, signal and image processing.

Evgeny Semenishchev received his BS in radio engineering from the South-Russian State University of Economics and Service in 2005, and MS in 2007 (Russia Federation). He received the Ph.D. degree in technics from the Southern Federal University (Russian Federation) in 2010. His research interests include image processing and medical imaging.

Sergey Makov was born in 1978. In 2001 he has graduated Don State University of Service as radio engineer. Since then he is working in the engineering company as designer of telecommunication hardware. He has got PhD in 2011. Since then he has worked as a professor assistant in the department of electronic systems of Don State Technical University.

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Reiner Creutzburg is a Full Professor of Computer Science at the Brandenburg University of Applied Sciences, Brandenburg (Germany) since 1992. He is a consultant to Government and Industry for more than 15 years. His main topics of interest and areas of research are Multimedia Signal and Image Processing, Algebraic Signal Processing, Media Compression, and Computer and Multimedia forensics. He is a Head of the newly established Computer and Media Forensics Lab in his University. He is a member of SPIE and IEEE.