Authenticate images based on their semantic segmentation in deep learning neural networks with their pre-processing with use of filtering methods

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In modern domestic and international pre-trial practice and legal proceedings, physical evidence used in the form of electronic documents or their digital images. The issue of authenticating such images is hampered by possibilities of using artificial intelligence based editors to fake images making it impossible or significantly complicate the search for changed areas by forensic experts. Research issue considered by the authors is the authenticity assessment of digital images based on the use of their pre-processing (filtering) methods and artificial intelligence technologies for further analysis and determination of edited areas.

This research paper purpose is to develop information technology for finding editing zones based on a combination of imaging techniques and neural network models for use in image authenticity research.

Research paper novelty is to develop a technology to combine several methods of pre-processing images (in particular, ELA and PCA) to create an input stream of a deep learning neural network and to assess effectiveness of identifying editing zones created by the digital painting editor (Inpainting).

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Efficiency of 10 editing zone detectors using combination of ELA and PCA methods with different models of neural networks for recognizing editing zones has been developed and investigated. The best results (probability of recognition 0.916) within the used computing resources were obtained by detector based on the EfficientNet model.

IT Effectiveness and related software for assessing authenticity of images based on a combination of image pre-processing methods and models of artificial neural networks in semantic classification and segmentation mode has been developed and evaluated.

Keywords: *image authenticity; artificial intelligence; neural networks; ELA; PCA; Inpainting.*

Research Problem Formulation

Scientific issue considered in this research paper is the authenticity assessment of digital images based on the use of their pre-filtering methods and artificial intelligence technologies. Currently, physical evidence is used in the form of electronic documents or their images, photographs, videos, scanned copies that have a digital formation nature.

At the same time, scientific and technological progress in the field of photography and video recording, methods and means of software editing of digital images creates ample opportunities for manipulating content of digital images and actualizes their authentication issue. The issue is further hampered by the use of artificial intelligence methods for editing images to prevent or complicate the search for altered areas.

Analysis of Essential Researches and Publications

Research of photographic images is devoted to fundamental research papers of D. Ya. Myrskyi, P. F. Sylkyn, Ye. M. Dmytriiev, etc. The process of researching digital photos is much more complicated because they have a different creation nature. Researches on digital photographs in order to identify signs of installation was considered by A. O. Safonov, V. H. Kalenskyi, Ye. M. Dmytriiev, S. M. Bobrytskyi, S. V. Chornyi, et al. Best practices of domestic and foreign researchers are devoted to research on additional data (file metadata) describing conditions and methods of file obtaining. This is devoted to research papers of R. Blythe, J. Fridrich, A. A. Kobozev, N. Krawetz, Ye. M. Dmytriiev, G. K. Wallace [1].

1 E.g., Мирский Д. Я. Судебная фототехническая экспертиза : метод. пособ. для экспертов. Москва, 1982. 167 с. ; Силкин П. Ф. Судебно-исследовательская фотография : учебник. Волгоград, 1979. 335 с. ; Дмитриев Е. Н. Судебная экспертиза фотографических изображений: современное состояние и возможности решения экспертных задач. *Судебная экспертиза*. 2009. № 3. С. 73—79 ; Сафонов А. А., Колотушкин С. М., Кочубей А. В. Компьютерные технологии в криминалистической фотографии: теоретические и прикладные вопросы : учеб. пособ. Волгоград, 2005 ; Каленський В. Г. Дослідження цифрових фотознімків з метою виявлення ознак монтажу. *Судова експертиза. Сучасний стан та перспективи розвитку* : мат-ли міжнар. наук.-практ. конф. Київ, 2010. С. 191—192 ; Бобрицкий С. М., Черный С. В. Методические аспекты комплексного исследования с целью выявления признаков монтажа в цифровой фотографии. *Теорія та практика судової*

Currently, the closest to this research area is *Methods of research of digital photographic images and technical means of their manufacture* [2] and *Methods of research of signs of digital image editing based on noise entropy analysis*[3]. For supporting the latter, the authors have developed appropriate software [4] for comparative research with known and modified methods of image quality assessment (33 methods of local focusing quality, 17 are noise characteristics, 15 are analysis by Discrete Cosine Transform (DCT), 14 are image entropy analysis).

These methods correspond to tasks of forensic examination of digital images. However, it should be noted that use of various methods of these methods (Error Level Analysis (ELA), Principal Component Analysis (PCA)) requires considerable expert experience and research time.

Performed researches is a significant contribution to development of theoretical foundations for specific expertise use in forensic science. At the same time, the analysis of possibilities of research on authenticity of digital images based on the use of their pre-filtering methods and artificial intelligence technologies is an issue that still requires in-depth scientific research. Given the above, further improvements, in our opinion, require research on use of artificial intelligence technologies in combination with the above methods of pre-processing images to recognize altered areas of digital images.

Article purpose

This article purpose is IT development for finding editing zones based on models of neural networks while research on authenticity of images. In our opinion, the main attention of scientists should be paid to development of methods and specialized software for advanced image analysis using modern methods of image processing.

Main Content Presentation

One of the most important tasks of modern forensic research on digital photographs and videos is to detect the signs of their photomontage or editing.

Given the relative ease of creating, modifying, and distributing digital records, investigators or courts have a relevant question about their authenticity. The *authentic* term in relation to phonograms in the sense of *true*, *reliable* is now widely used

експертизи і криміналістики. 2010. Вип. 10. С. 633—639 ; Blythe P., Fridrich J. Secure digital camera. *Digital Forensic Research Workshop* (Baltimore, USA, 11—13.08.2004). P. 12 ; Кобозева А. А. Использование особенностей возмущений сингулярных чисел матрицы цифрового изображения для обнаружения его фальсификации. *Искусственный интеллект*. 2008. № 1. С. 145—153; Krawetz N. A Picture's Worth... Digital Image Analysis and Forensics. 2007. URL: https://www.hackerfactor.com/papers/bh-usa-07-krawetz-wp.pdf (date accessed: 17.01.2022) ; Дмитриев Е. Н. Метаданные как средство индивидуализации цифровых изображений в судебной фотографии. *Теория и практика судебной экспертизы в современных условиях* : мат-лы междунар. науч.-практ. конф. Москва, 2007. С. 531—534 ; Wallace G. K. The JPEG Still Picture Compression Standard. IEEE Transactions on Consumer Electronics. 1991.

2 Методика досліджень цифрових фотозображень та технічних засобів їх виготовлення. Реєстр методик проведення судових експертиз. URL: https://rmpse.minjust.gov.ua/page/41 (date accessed: 17.01.2022).

3 Методика дослідження ознак монтажу цифрових зображень на основі аналізу ентропії шумів. Реєстр методик проведення судових експертиз. URL: https://rmpse.minjust.gov.ua/page/43 (date accessed: 17.01.2022).

4 IFD TEC. URL: https://5.189.182.106 (date accessed: 17.01.2022).

in English law, although it was originally adopted in theory of forensic research by Polish forensic scientists [5], later it was also used by American forensic experts [6].

Current progress of technical means of photo, video, recording and telecommunication technologies expands as possibilities of traditional data capture tools as emergence of new ways to obtain records (mobile, network, specialized) with new data formats. This requires constant updating of specific expertise of experts in the field of research on digital images, video and sound recordings. This issue is of particular relevance due to the fact that criminals are improving the ways of committing crimes, increasingly masking their traces, using modern achievements of science and technology. Therefore, without use of the latest means, it is often impossible or extremely difficult to document the actions of criminals and bring them to criminal responsibility.

Traditionally, the forensic photography subject were material data (positives, negatives, various technical means for their manufacture), that were procedurally enshrined in the case files. However, current methods of studying photographic images obtained using analog technology are ineffective for research on digital photos. The main modern objects of these researches are:

- digital photographs (photographs obtained as a result of photographing objects at a specific point in time and presented on media in the form of computer files of graphic formats);
- digital video and sound recordings recorded on physical media or directly on recording devices; individual frames or groups of frames from digital video recordings of objects at specific time intervals, represented on media in the form of computer files of graphic formats;
- photographing technical means (digital cameras);
- video recording technical means (digital video cameras, video recorders, etc.).

Comparative research objects include:

- digital photographs (photographs obtained as a result of photographing objects at a specific point in time and presented on media in the form of computer files of graphic formats);
- digital photo images presented on media in the form of computer files of graphic formats, methods and conditions for obtaining are determined.

Digital graphic file as research object differs significantly from traditional photograph, since in addition to information about the image/drawing itself (format, width, height, number of pixels per inch, number of bits per pixel, color model, and other characteristics and comments), such a file also contains information about its metadata (name, size, type, creation dates and last changes, etc.). The most interesting of them are EXIF data [7], that in research papers of domestic and foreign scientists are mentioned as

5 Гургуль К. Из процессуальной и криминалистической проблематики магнитофонной записи. *Сборник переводов*. № 213. Москва, 1973. С. 61—81 ; Проблемы криминалистики. Варшава, 1971. № 90. С. 159—183.

6 Hollien H. The Acoustics of Crime: The New Science of Forensic Phonetics. Florida, 1994.

7 EXIF (Exchangeable Image File Format) is a standard that allows to add additional information (metadata) to images and audio files, comments on this file, and describes conditions and methods of its obtaining, authorship, etc.

additional data formed as a result of built-in software operation of modern digital photo or video recording device. They allow you to emphasize individual features of the digital camera or applications that saved the latest graphic revision of the file using:

- digital camera manufacturer name and its model;
- interoperability analysis of technical capabilities of a particular digital camera with those recorded in EXIF data;
- name and version of built-in digital camera application;
- highlighting the signature with recording of data about the application or device that stored the latest graphic file revision.

Digital image or video editing programs often change file metadata fields, the order of fragments and the information on adding new ones and/or completely their deleting. A significant number of applications editing digital records leave their records (tags) in the file service part and information about the previous application can be deleted.

Graphic file can be considered as an object, which research is associated with assessment of the change in the noise background of digital matrix of the video or photographic recording device.

Researches on file structure (in particular, header metadata, recorded content, metadata multiplexed with recorded content, as well as possible data at the end of digital recording) belong to observational analysis, they should be compared with sample records made from recording devices provided for research or other test records. If the source recording device is unavailable or cannot be used, forensic expert can use the same device model.

The most challenging tasks are expert tasks related to technical research on digital images and video recordings. Currently, automation of researches on authenticity of digital images (individual frames from video recordings) is an urgent scientific task. Many separate methods for examining authenticity of images have been developed that solve issues only in certain conditions. There is a need for forensic expert practice in automating generalization of results of such individual researches on one object to increase reliability of the decision made by forensic expert.

The method of studying authenticity of digital images proposed in this paper is based on artificial intelligence principles, it is based on automatic generalization of individual research results of authenticity of digital images obtained by various methods of their preliminary digital analysis (filtering) and on the use of convolutive neural networks of deep learning to find editing zones. As an IT in image authentication research, this is a combination of image preprocessing methods and neural network models.

Urgency of conducting research in this area is due to the need to provide forensic expert practice with modern domestic methodological developments for assessing authenticity of images. Currently, we have accumulated practical experience of expert work of the specialists of National Scientific Center «Hon. Prof. M. S. Bokarius Forensic Science Institute» on analysis of images during performance of various forensic expert tasks within research on video, sound recordings and digital images that should be supplemented with technology of automatic generalization of results, systematize world experience and develop a comprehensive approach to solve relevant expert tasks.

An important stage while software development using artificial neural network models is database preparation of edited images necessary for their training and testing. Therefore, it is necessary select the appropriate editor and use it to create a set of edited images. We consider the editor of NVIDIA Inpainting to be the most effective in terms of quality of editing [8], that is why

8 Inpainting. URL: https://en.wikipedia.org/wiki/Inpainting (date accessed: 17.01.2022) ; Image Inpainting. URL: https://www.nvidia.com/research/inpainting/ (date accessed: 17.01.2022).

we will consider methodology of data preparation on its example. It is necessary to select or create a set of original images in advance (in our study, such a set was created by photographing various scenes with the Xiaomi Redmi Note 7 Pro smartphone, the size of master copy is 3000 × 4000 pixels).

Each of images is transformed using editor working window according to the principle shown in Fig. 1 into an edited image with imitation of deleted areas (Fig. 1, c) and into a mask of deleted areas (Fig. 1, d). After completing this step, the masks of edited zones and edited images are saved through the clipboard and the local Paint editor as separate images with the same names but in different folders. The resulting set of edited images and masks of deleted areas are subsequently used to train classifiers of the neural network model.

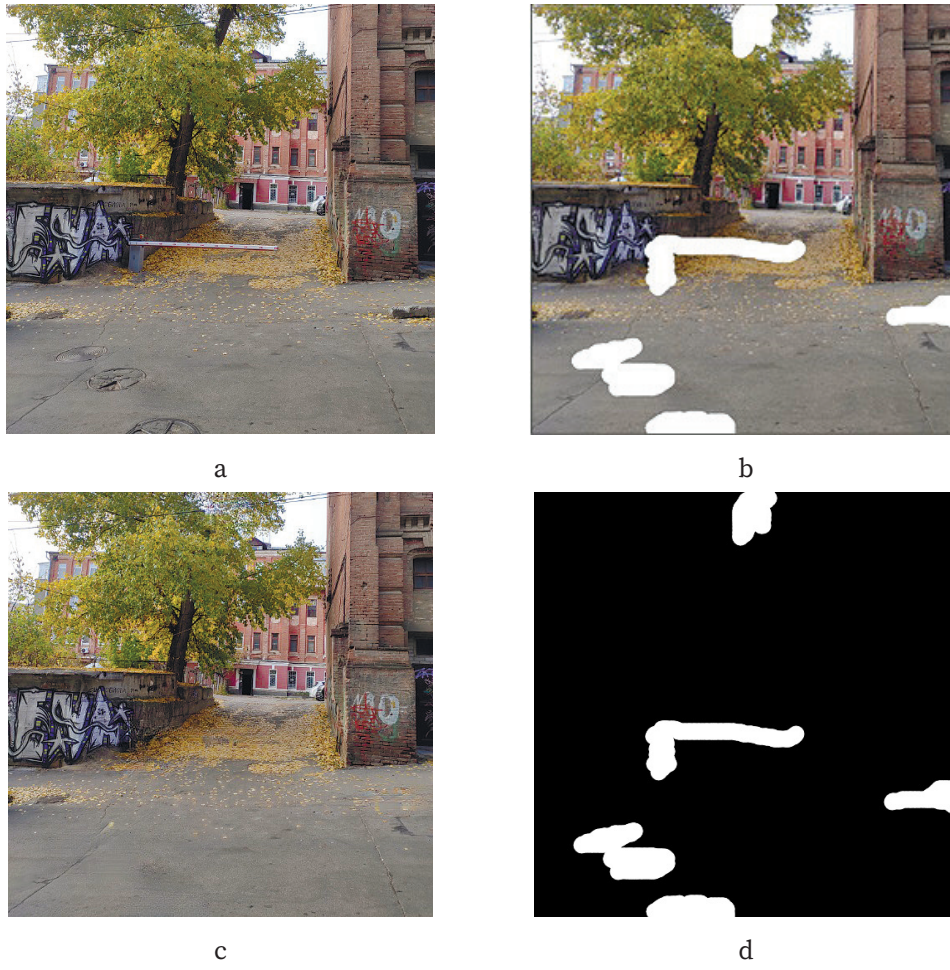

Fig. 1. Editing results: *a*) is image master copy, *b*) is master copy with the mask of deleted fragments, *c*) is image automatically simulated by editor, *d*) is mask of deleted zones)

Let us consider research prerequisites and criteria for assessing recognition quality. The research was performed under the following conditions:

- editing images using NVIDIA digital painting technology;
- image preprocessing by ELA and PCA methods.

Semantic classification quality and segmentation of editing zones was assessed according to the following criteria:

- portion of correctly classified edited pixels relative to the actual number of edited pixels (PM);
- relative error in defining the edit mask (D);
- portion of erroneously classified pixels outside valid editing zones (NM);
- visual assessment by forensic expert of the fact of editing according to the results of semantic segmentation (V).

Basic ratios (in terms of Python code) for the first criterion:

PM=np.sum(c1)/np.sum(im1N),c1=np.multiply(im4N,im1N);

where: im1N is real editing mask;

im4N is evaluated editing mask;

np.multiply() is array element-by-element multiplication operator;

np.sum() is an array summation operator.

Basic ratios (in terms of Python code) for the first criterion:

D=np.sum(np.abs(c2))/np.sum(im1N), c2=np.subtract(im4N,im1N);

np.multiply() is array element-by-element multiplication operator;

np.abs() is an operator for calculating the absolute values of array elements.

Basic ratios (in terms of Python code) for the first criterion:

i=np.multiply(im1N-1,-1);

c3=np.multiply(im4N,im1neg);

NM=np.sum(c3)/np.sum(i).

The main ratios for the fourth criterion are:

- V = 1, editing area is visually determined based on the segmentation results;
- V = 0, editing zone is not visually defined based on segmentation results.

The expert's visual assessment of the fact of editing based on results of semantic segmentation V is used to calculate the probability of recognition for each of the experimental models of neural networks.

Based on a preliminary assessment of software performance in conditions of available computing capabilities of the Kaggle public cloud resource for training models of neural networks, the authors chose the models of the following types for research: FPN-EfficientNetB4 [9], FPN-EfficientNetB4-96 [11], LinkNet-EfficientNetB3 [11], Unet-EfficientNetB4 [11], Keras Unet Collection Attunet [10], Keras Unet Collection Vnet [11], LinkNet DenseNet-201 [12], DeepLabV3Plus-MobileNetV1 [13], BiSegNet-MobileNetV1, BiSegNet-Xception [14].

9 TF Semantic Segmentation. URL: https://pypi.org/project/tf-semantic-segmentation/ (date accessed: 17.01.2022).

10 Keras-unet-collection 0.1.13. URL: https://pypi.org/project/keras-unet-collection/ (date accessed: 17.01.2022).

11 Segmentation-models. URL: https://pypi.org/project/segmentation-models (date accessed: 23.03.2021).

12 Ibid. URL: https://github.com/qubvel/segmentation_models (date accessed: 17.01.2022).

13 Amazing-Semantic-Segmentation. URL: https://github.com/luyanger1799/Amazing-Semantic-Segmentation (date accessed: 17.01.2022) ; Ibid. URL: https://pypi.org/project/semantic-segmentation (date accessed: 25.03.2021).

14 Chollet F. Xception: Deep Learning with Depthwise Separable Convolutions. URL: https://arxiv.org/pdf/1610.02357.pdf (date accessed: 22.03.2021).

Let us consider the summarized research results. Analysis of the results of testing of selected models of artificial neural networks in certain conditions indicates the presence of scattering of quality indicators on the used set of test images created by the Inpainting editor. Therefore, it is advisable to consider the averages for each network and the test image set at all. The average values of PM, D, NM, V for testing conditions are presented in Table 1, for selective ranges (close to the highest values of the probability of recognition) in Fig. 2—4.

Table 1

Averages of studied networks

Network Model Name	PM	D	NM	V
FPN-EfficientNetB4-16	0.446	0.718567	0.01067	0.75
FPN-EfficientNetB4-96	0.446	0.718567	0.01067	0.791667
LinkNet-EfficientNetB3	0.532237	0.824179	0.022165	0.833333
Unet-EfficientNetB4	0.522778	0.62255	0.011115	0.916667
Keras Unet Collection Attunet	0.044962	0.991533	0.002467	0.458333
Keras Unet Collection Vnet	0.01882	1.063992	0.0044	0.25
LinkNet-DenseNet-201	0.247155	1.012773	0.018333	0.791667
DeepLabV3Plus-MobileNetV1	-0.49301	11, 97283	-0.86514	0.25
BiSegNet-MobileNetV1	-0.31014	1.928322	-0.01952	0.333333
BiSegNet-Xception	-0.96842	15.61361	-1.05829	0.458333

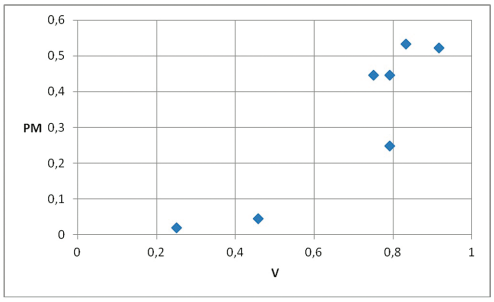

Fig. 2. Dependence of the average PM on the average probability of recognition V

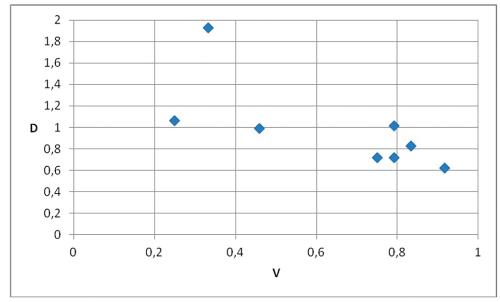

Fig. 3. Dependence of the average D on the average probability of recognition V

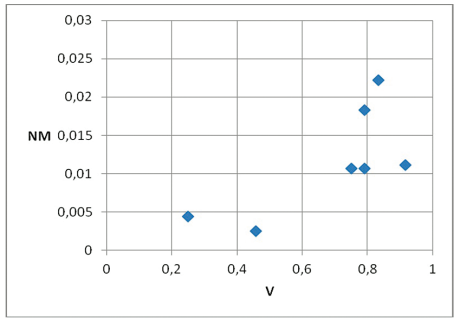

Fig. 4. Dependence of the average NM on the average probability of recognition V

Analysis of the data shown in Fig. 2—4 makes possible to distinguish the relative absolute total error of detection of the editing zone D as the most accurate and unambiguous indicator of the quality of the semantic classifier. It is possible to use playback accuracy of the PM editing zones. The least unambiguous relative to the average probability of recognition was the NM indicator.

Authenticity evaluation example of zones in the edited image (a deleted image of a concrete wall with pictures on the bank of the canal and 2 windows on the wall of the building) for the best D networks is shown in Fig. 5—6.

Thus, the best of studied classifiers of semantic type with data pre-processing according to the ELA and PCA algorithms within selected models of neural networks was the model of the artificial neural network of the Unet type with the EfficientNetB4 feature classifier.

a b

Fig. 5. Test image: *a*) is original; *b*) is edited image

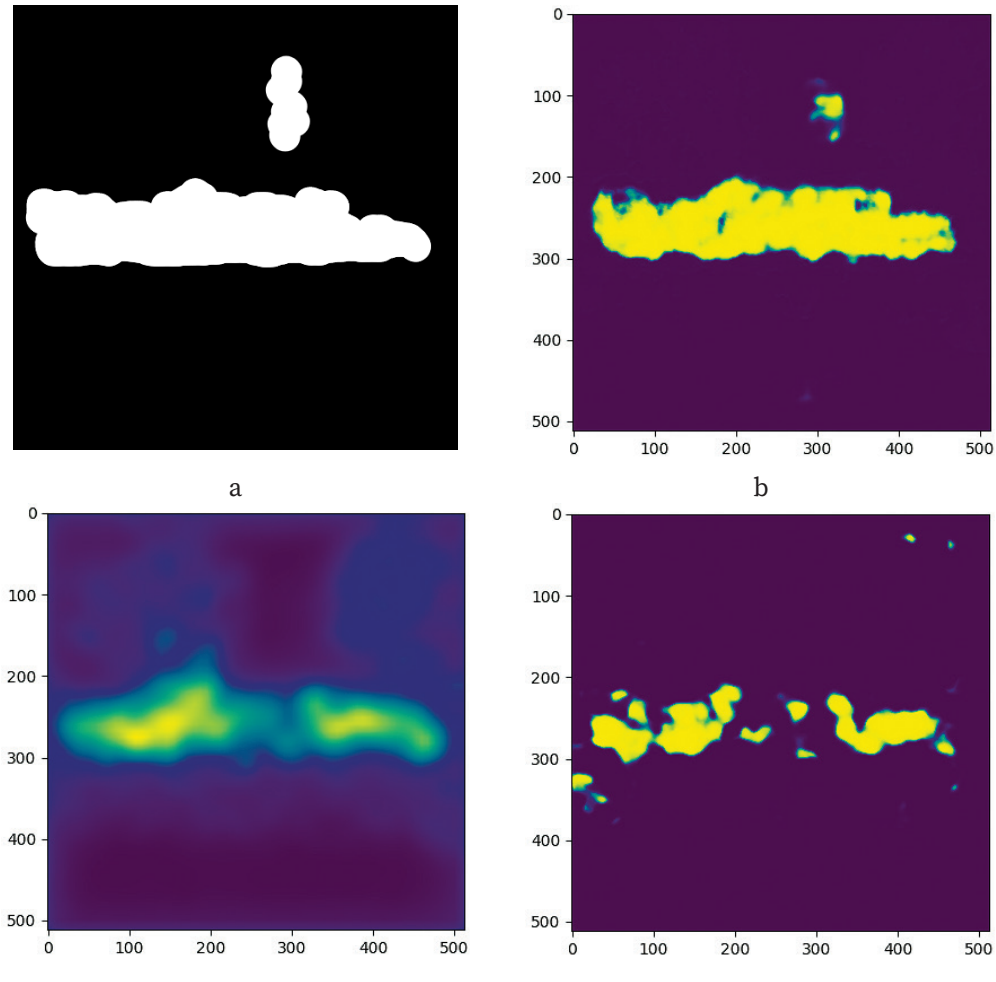

Fig. 6. Results of semantic segmentation of the edited test image:
a) is real editing zone; *b)* is Unet-EfficientNetB4 network;
c) is BiSegNet-Xception network; *d)* is AttUnet network

Conclusions

This research paper presents the research results of effectiveness of combining methods of pre-processing images and neural networks of deep learning to detect signs of editing, developed information technology and software for assessing the authenticity of images based on a combination of methods of pre-processing images and models of artificial neural networks in the mode of semantic classification and segmentation.

The achieved probability of recognition of edited areas of the Unet-type network with the EfficientNetB4 feature classifier

and pre-processing of images by ELA and PCA methods was 0.91. 4 performance indicators of the semantic classifier are studied and it is determined that the relative absolute total error of detection of the editing zone D is the most accurate and unambiguous numerical work quality indicator.

Автентифікація зображень на основі їх семантичної сегментації у нейронних мережах глибокого навчання з їх попереднім обробленням за методами фільтрації

Сергій Чорний, Ольга Брендель, Давіт Гратіашвілі

У сучасній вітчизняній та міжнародній досудовій практиці та судових провадженнях використовують речові докази у вигляді електронних документів або їх цифрових зображень. Проблему автентифікації таких зображень ускладнено можливостями використання для підробки зображень редакторів на основі штучного інтелекту, що унеможливлюють або суттєво ускладнюють пошуки судовими експертами змінених ділянок. Науковою проблемою, розглянутою авторами, є оцінювання автентичності цифрових зображень на основі використання методів їх попереднього оброблення (фільтрації) і технологій штучного інтелекту для подальшого аналізу та визначення редагованих ділянок.

Метою роботи є розроблення інформаційної технології пошуку зон редагування на основі поєднання методів попереднього оброблення зображень і моделей нейронних мереж для використання у дослідженнях автентичності зображень.

Новизна роботи полягає у розробленні технології поєднання кількох методів попереднього оброблення зображень (зокрема, ELA та PCA) для створення вхідного потоку нейронної мережі глибокого навчання й оцінювання ефективності виявлення зон редагування, створених редактором цифрового живопису (Inpainting).

Розроблено та досліджено ефективність роботи 10 детекторів зон редагування, що використовують поєднання методів ELA та PCA з різними моделями нейронних мереж розпізнавання зон редагування. Найкращі результати (імовірність розпізнавання 0,916) у межах використаних обчислювальних ресурсів отримано детектором на основі моделі типу EfficientNet.

Розроблено й оцінено ефективність інформаційної технології та відповідного програмного забезпечення для оцінювання автентичності зображень на основі поєднання методів попереднього оброблення зображень і моделей штучних нейронних мереж у режимі семантичної класифікації та сегментації.

Ключові слова: *автентичність зображення; штучний інтелект; нейронні мережі; ELA; PCA; Inpainting.*

Аутентификация изображений на основе их семантической сегментации в нейронных сетях глубокого обучения с их предварительной обработкой методами фильтрации

Сергей Чёрный, Ольга Брендель, Давит Гратиашвили

В современной отечественной и международной досудебной практике и судебных разбирательствах используют вещественные доказательства в виде электронных документов или их цифровых изображений. Проблема аутентификации таких изображений осложняется существующими возможностями использования для подделки изображений редакторов на основе искусственного интеллекта, что делает невозможным или существенно усложняет поиски судебными экспертами изменённых участков.

Научной проблемой, рассмотренной авторами, является оценивание подлинности цифровых изображений на основе использования методов их предварительной обработки (фильтрации) и технологий искусственного интеллекта для дальнейшего анализа и определения отредактированных участков.

Целью работы является разработка информационной технологии поиска зон редактирования на основе сочетания методов предварительной обработки изображений и моделей нейронных сетей для использования в исследованиях подлинности изображений.

Новизна работы заключается в разработке технологии сочетания нескольких методов предварительной обработки изображений (в частности, ELA и PCA) для создания входного потока нейронной сети глубокого обучения и оценивания эффективности выявления зон редактирования, созданных редактором цифровой живописи (Inpainting).

Разработана и исследована эффективность работы 10 детекторов зон редактирования, использующих сочетания методов ELA и PCA с различными моделями нейронных сетей распознавания зон редактирования. Наилучшие результаты (вероятность распознавания 0,916) в пределах использованных вычислительных ресурсов получены детектором на основе модели типа EfficientNet.

Разработана и оценена эффективность информационной технологии и соответствующего программного обеспечения для оценивания подлинности изображений на основе сочетания методов предварительной обработки изображений и моделей искусственных нейронных сетей в режиме семантической классификации и сегментации.

Ключевые слова: *подлинность изображения; искусственный интеллект; нейронные сети; ELA; PCA; Inpainting.*

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The authors declare that they have no conflict of interest.

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