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IMAGE RESTORATION ALGORITHMS (INPAINTING): CLASSICAL AND NEURAL NETWORK APPROACHES

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Анотація

У роботі розглянуто алгоритми inpainting, що застосовуються для відновлення пошкоджених або видалених фрагментів зображень у сучасних графічних редакторах. Проаналізовано еволюцію підходів до заповнення відсутніх областей - від класичних методів на основі диференціальних рівнянь (PDE) до patch-based алгоритмів та сучасних нейромережевих моделей. Визначено особливості кожного підходу, їх переваги та обмеження під час обробки текстур, структурних елементів і складних сцен. Окрему увагу приділено застосуванню inpainting в інтелектуальних інструментах редагування зображень, зокрема автоматичному видаленню об'єктів та реконструкції фону. Показано, що впровадження методів глибинного навчання суттєво підвищило якість та реалістичність відновлених зображень, що робить дану технологію одним із ключових напрямів розвитку сучасних графічних редакторів.

Ключові слова: inpainting, обробка зображень, реконструкція зображень, графічні редактори, нейромережі, відновлення текстур.

Abstract

The paper considers inpainting algorithms used to restore damaged or deleted image fragments in modern graphic editors. The evolution of approaches to filling missing areas is analysed, from classical methods based on differential equations (PDE) to patch-based algorithms and modern neural network models. The features of each approach, their advantages and limitations when processing textures, structural elements and complex scenes are identified. Particular attention is paid to the application of inpainting in intelligent image editing tools, in particular, automatic object removal and background reconstruction. It is shown that the implementation of deep learning methods has significantly improved the quality and realism of restored images, making this technology one of the key areas of development for modern graphic editors.

Keywords: inpainting, image processing, image reconstruction, graphic editors, neural networks, texture restoration.

Modern graphic editors are widely used for image editing, in particular for removing unwanted objects and subsequently restoring the background. For this purpose, inpainting technology is applied – an algorithmic filling of missing or damaged areas of an image based on information from surrounding regions.

One of the first scientifically grounded approaches to inpainting were methods based on mathematical models, particularly on equations that describe the propagation of information from the boundary of the damaged region into its interior [1]. In these algorithms, the image structure is continued according to the directions of brightness gradients, which makes it possible to effectively restore small defects.

Further development led to methods based on the Fast Marching Method, which provide faster and more stable filling of small regions [2]. Such approaches work well for removing scratches or minor damage, however, they do not ensure high-quality reconstruction of complex textures.

The next stage of development was represented by exemplar-based or patch-based algorithms [3]. Their principle consists in copying fragments from undamaged parts of the image into the restoration area. The algorithm finds regions similar in texture and color and gradually fills the selected area with the corresponding fragments. This approach significantly improved the quality of texture reconstruction and became the basis of many automatic object removal tools in graphic editors.

With the development of deep learning, neural network approaches to inpainting have emerged. In [4], the use of contextual encoders was proposed, which allow restoring missing parts of an image while taking into account the global context of the scene. Further studies have shown that the use of attention mechanisms improves the accuracy of reconstruction of complex structures and textures [5].

A comparison of different approaches shows that mathematical methods [1; 2] are effective for small defects and are characterized by relative simplicity of implementation. Patch-based algorithms [3] perform better when working with textured surfaces; however, they depend on the presence of appropriate fragments in the image. Neural network methods [4; 5] provide the highest quality of reconstruction due to the consideration of semantic context, but they require significant computational resources. For clarity, the main characteristics of different approaches to image restoration are presented in Table 1.

Table 1 – Comparison of image inpainting methods

Method	Principle	Advantages	Limitations
PDE-based methods	Propagation of information from the boundary of the damaged region using differential equations	Simple implementation, effective for small defects	Poor performance for complex textures
Fast Marching method	Gradual filling of missing regions based on brightness gradients	High processing speed, stable algorithm	Limited ability to reconstruct complex structures
Patch-based methods	Copying texture fragments from undamaged areas of the image	Good reconstruction of textures and repeating structures	Requires similar fragments in the image
Neural network methods	Use of deep learning models (CNN, GAN) to reconstruct missing areas using global context	High quality and realistic reconstruction	High computational cost

Thus, the paper analyzes the main approaches to image restoration using the inpainting method, including mathematical models, patch-based algorithms, and modern neural network methods. It is shown that classical algorithms are effective for removing small defects and have low computational complexity; however, their capabilities are limited when reconstructing complex textures and structures. Patch-based approaches significantly improve the quality of texture restoration but depend on the availability of similar fragments in the original image. The most promising approaches are neural network methods that use deep learning and contextual analysis mechanisms to restore complex scenes. The use of such algorithms in modern graphic editors provides a high level of automation in image editing and opens new possibilities for intelligent processing of graphical information.

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