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AN IN-DEPTH LOOK INTO COMBINING IMAGE PROCESSING AND WAVELET TRANSFORMATION

Review article

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Abstract

This article discusses the substantial influence of wavelet transformation in the field of image processing. A thorough understanding of the mathematical foundations of wavelet transformation is explored, with a focus on its unique capacity to do multi-resolution analysis. The adaptability of wavelets to a wide range of problems is further demonstrated by showcasing its applications in feature extraction, denoising, and picture compression. A comparison with other techniques, provides insight on the spatial localization properties that set wavelet transformation apart from the rest. Future directions, such as adaptive transformations and integration with deep learning, as well as challenges, such as computing complexity and wavelet selection, are also covered. This review encourages further investigation, collaboration, and learning in the developing field of wavelet-based image processing, emphasizing its revolutionary significance and ongoing potential to dictate the course of visual data analysis.

Keywords: image processing, wavelet transformation, mathematical foundation.

УГЛУБЛЕННЫЙ АНАЛИЗ СОЧЕТАНИЯ ОБРАБОТКИ ИЗОБРАЖЕНИЙ И ВЕЙВЛЕТ-ПРЕОБРАЗОВАНИЙ

Обзор

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Аннотация

В этой статье рассматривается существенное влияние вейвлет-преобразований на область обработки изображений. Рассматриваются математические основы вейвлет-преобразования с акцентом на его уникальную способность к анализу в нескольких разрешениях. Адаптивность вейвлетов к широкому кругу задач демонстрируется на примере их применения в экстракции признаков, обесцвечивании и сжатии изображений. Сравнение с другими методами дает представление о свойствах пространственной локализации, которые отличают вейвлет-преобразование от других. Также рассматриваются будущие направления, такие как адаптивные преобразования и интеграция с глубоким обучением, а также проблемы, такие как сложность вычислений и выбор вейвлетов. Этот обзор призван способствовать дальнейшим исследованиям, сотрудничеству и обучению в развивающейся области обработки изображений на основе вейвлетов, подчеркивая ее революционное значение и сохраняющийся потенциал определять ход анализа визуальных данных.

Ключевые слова: обработка изображений, вейвлет-преобразование, математические основы.

Introduction

As an important area of study in computer science and technology, image processing has become a creative force that is changing many different sectors. Fundamentally, image processing involves modifying visual input to extract meaningful information, enhance perceptual quality, and facilitate effective decision-making in several domains [1]. In this vast and developing subject, wavelet transformation is one method that has drawn a lot of attention because of its unique features.

The first section of this literature review provides a thorough overview of image processing, outlining its goals, definition, and evolutionary history. Image processing is an important field that affects many different industries. To enhance the quality and usability of images, practitioners and researchers have developed new methods that can handle different image structures, gather detailed features, and overcome issues such as noise and other defects [2].

Moving on, the concepts of wavelet transformation come into focus. The goal is to offer a clear understanding of wavelets by delving into the mathematical concepts that underpin this approach. Wavelet transformation has the advantage of being flexible with non-stationary signals and efficient in expressing data with both global and local properties [3], which opens the door to a thorough examination of its uses in image processing.

Finally, wavelet transformation in image processing is explored in great detail, highlighting its applications, complexities, and potential future developments. In the following sections, the present state and the exciting future potential of the complex tapestry of wavelet transformation in image processing will be revealed.

Fundamentals of image processing

One of the primary areas of study in computer science is image processing, which is the management and analysis of a visual input to extract relevant information. Improving image quality, facilitating pattern recognition, and easing decision-making processes for a variety of applications are among the objectives of image processing [4]. The constant search for methods that can more reliably collect and analyze visual data has supported the advancement of image processing. These are the basic ideas of image processing.

Definition and goal

At its core, image processing is using computer programs to modify and analyze a visual input. The two main objectives of image processing are image restoration, which attempts to restore or repair images that have been compromised by noise, blur, or other factors, and image enhancement, which seeks to increase the overall quality of an image [2].

Processes utilized for visual data modification range from simple adjustments like scaling and cropping to more sophisticated methods like filtering, segmentation, and transformation [5]. These procedures are essential for feature extraction, pattern recognition, and object identification, which advances computer vision, remote sensing, and medical imaging [1].

Historical Development

During the course of time, significant turning points in the field of image processing has developed it into a thriving, interdisciplinary field. Early developments in the middle of the 20th century focused on basic picture-enhancing methods, such as histogram equalization and contrast stretching [6]. In the 1970s, photo compression and encoding techniques advanced further [7]. Researchers have established the foundation for standards like JPEG by studying the mathematical representations of images and creating successful data compression methods like the Discrete Cosine Transform (DCT) [8].

The need for effective data representation and feature extraction increased as image processing advanced through the use of artificial intelligence and machine learning [9] and transformed into a versatile tool for resolving problems in the age of big data and complex visual information [10].

The following sections will explore further into the powerful role of wavelet transformation in this dynamic environment, examining its mathematical underpinnings, practical uses, and relative advantages.

Fundamentals of wavelet transformation

Understanding the impact of wavelet transformation on image processing involves an exploration of its mathematical underpinnings. The primary objective of wavelet transformation is to analyze signals or images at different resolutions. This is accomplished by gradually dividing the original signal into approximation and detail coefficients using a hierarchical decomposition approach [11].

Two functions are convolved in the wavelet transform: wavelet (ψ , psi) and scaling (ϕ , phi). The wavelet function records the high-frequency components of the signal, whereas the scaling function extracts the low-frequency components [11]. A series of expansions and translations of these functions result in the transformation, which generates an analysis with many resolutions.

Equation 1 gives the continuous wavelet transformation (CWT) of the signal [12].

$$CWT(a, b) = \int_{-\infty}^{\infty} f(t) \cdot \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) dt \quad (1)$$

where a is the scaling factor, b is the translation parameter, and $\psi(t)$ is the wavelet function. The integral is taken over all values of t .

To simplify computation, the CWT is frequently discretized in practical applications. The discrete wavelet transformation (DWT) splits a signal into approximation (A) and detail (D) components via convolution and down sampling [13].

Let $x[n]$ represent a discrete signal. The DWT is calculated using equations 2 and 3.

$$A_{j+1}[n] = \sum_k h[k] \cdot A_j[2n - k] \quad (2)$$

$$D_{j+1}[n] = \sum_k g[k] \cdot A_j[2n - k] \quad (3)$$

The approximation and detail coefficients at the $(j+1)^{th}$ level of the decomposition are represented by the variables $A_{j+1}[n]$ and $D_{j+1}[n]$ in equations 2 and 3, respectively. The filters $h[k]$ and $g[k]$ are known as the scaling and wavelet coefficients. The down sampling procedure and the degree of decomposition are indicated by the subscript j and $[2n - k]$.

This formulation can analyze and portray complicated signals and images of real-world visual content owing to the mathematical underpinnings of wavelet processing. The various uses of wavelet transformation in image processing will be covered in detail in the next sections, which will also show how well it works to solve issues with feature extraction, denoising, and compression.

Applications of wavelet transformation in image processing

The versatility of Wavelet transformation can be seen by the many applications it has in image processing. It is a useful tool for carrying out sophisticated applications in a range of disciplines because of its exceptional capacity to represent both high-frequency and low-frequency components at different sizes [11]. The main applications of wavelet transformation, such as feature extraction, denoising, and image compression, are examined in this section.

Image Compression

Wavelet transformation is an efficient way to represent images with minimal data redundancy, and it has completely changed the field of image compression. Wavelet processing is frequently used with methods like JPEG2000 in image compression [14]. An image is divided into approximate and detail coefficients over a range of scales by wavelet-based

compression. Since high-frequency elements have little effect on overall perceptual quality, they may either be completely eliminated or quantized more aggressively to provide a compact representation. Wavelet transformation is a crucial part of modern picture compression standards as a result of this capability [15].

Denoising

Noise is a significant issue in image processing since it may deteriorate the quality of the image and make further analysis challenging. When the wavelet transform divides an image into approximation and detail coefficients, the low-frequency approximation coefficients resemble the actual signal, while the high-frequency detail coefficients frequently contain noise. Wavelet-based denoising algorithms may successfully remove noise while maintaining significant image features, since they rely on thresholding or altering detail coefficients [16].

Feature Extraction

Feature extraction is crucial for applications like object identification, content-based image retrieval, and image recognition. Using multi-resolution analysis, wavelets allow for easier to extract features at different resolutions, capturing both little details and more prominent patterns [17]. These offer a more comprehensive representation of the visual characteristics and resulting in a more accurate and precise image analysis.

The next part will present a comparative study between wavelet transformation and other image processing techniques in order to make clear its benefits and situate it within the framework of image processing approaches as a whole.

Future direction

There are promising new directions for future research and development in wavelet-based image processing [18].

Integration with Deep Learning: Combining the advantages of wavelet transformation with the learning capabilities of deep neural networks is an intriguing proposition. In order to improve image analysis, these hybrid approaches are currently being investigated.

Real-time Implementation: As algorithmic optimization and parallel processing advances, wavelet-based image processing may become increasingly useful for real-time applications.

Multimodal Image Processing: Extending wavelet transformation to handle multimodal data, including merging information from many image sensory systems, is a growing field of research.

Conclusion

Image processing, a crucial field of research in the fields of technology and computer science, is evolving into a creative force that is transforming numerous industries. It entails altering visual input in order to extract significant information, improve perceptual quality, and support efficient decision-making in a number of contexts. In the rapidly evolving field of image processing, wavelet transformation has shown to be a transformative journey, demonstrating its significant impact on the interpretation and manipulation of visual data.

Given its exceptional capacity to provide a multi-resolution analysis by simultaneously gathering high and low-frequency components, wavelet transformation is a potent tool for image processing. The aforementioned applications – denoising, feature extraction, and image compression – illustrate the versatility and potency of wavelet-based techniques in real-world settings.

In order to overcome the challenges and look ahead to the future of wavelet-based image processing, it is imperative that researchers focus on the integration of wavelet transformation with new technologies, such as deep learning, real-time implementations, and adaptive wavelet transforms.

In the broad field of image processing, wavelet transformation is a key technique that yields an advanced and efficient way to analyze visual data. Wavelet transformation holds great potential for the future of image processing as long as all involved parties can better comprehend its intricacies, find solutions to its problems, and explore novel applications. This study highlights the significance of wavelet transformation currently and open up opportunities for more investigation, cooperation, and innovation in the rapidly developing area.

Конфликт интересов

Не указан.

Рецензия

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Conflict of Interest

None declared.

Review

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Список литературы на английском языке / References in English

1. Basavaprasad B. A Study on the Importance of Image Processing and Its Applications / B. Basavaprasad, M. Ravi // International Journal of Research in Engineering and Technology. — 3. — 2014. — DOI: 10.15623/IJRET.2014.0315029.
2. Várkonyi-Kóczy A.R. New Advances in Digital Image Processing / A.R. Várkonyi-Kóczy // Memetic Computing. — 2. — 2010. — p. 283–304. — DOI: 10.1007/s12293-010-0046-3.
3. Wang J. Wavelet Transforms for Speech Signal Processing / J. Wang, S. Chen, J. Shyuu // Journal of the Chinese Institute of Engineers. — 1999. — 22:5. — p. 549-560. DOI: 10.1080/02533839.1999.9670493.
4. Feng Z. Pattern Recognition and Its Application in Image Processing / Z. Feng, X. Hua // Journal of Physics: Conference Series. — 2020. — 1518. DOI: 10.1088/1742-6596/1518/1/012071.

5. Kasik D.J. Data Transformations and Representations for Computation and Visualization / D.J. Kasik, D. Ebert, G. Lebanon, H. Park, W.M. Pottenger // *Information Visualization*. — 8:4. — 2009. — p. 275 - 285. DOI: 10.1057/ivs.2009.27.
6. Mustafa W.A. A Review of Histogram Equalization Techniques in Image Enhancement Application / W.A. Mustafa, M.M.M.A. Kader // *Journal of Physics: Conference Series*. — 1019. — 2017. — p. 25-27. DOI: 10.1088/1742-6596/1019/1/012026.
7. Rosenfeld A. Image Processing and Recognition / A. Rosenfeld // *Advances in Computers*. — 18. — 1979. DOI: 10.1016/S0065-2458(08)60581-1.
8. More N.K. JPEG Picture Compression Using Discrete Cosine Transform / N.K. More, S. Dubey // *International Journal of Science and Research*. — 2:1. — 2013.
9. Hassan A. Feature Extraction for Image Analysis and Detection using Machine Learning Techniques / A. Hassan, M. Sabha // *International Journal of Advanced Networking and Applications*. — 14:4. — 2023. — p. 5499-5508. DOI: 10.35444/ijana.2023.14401.
10. Yu J. Machine Learning for Big Visual Analysis / J. Yu, X. Mei, F. Porikli, J. Corso // *Machine Vision and Applications*. — 29. — 2018.— p. 929–931. DOI: 10.1007/s00138-018-0948-5.
11. Rao R.M. Three-scale Wavelet Transforms / R.M. Rao, J.S. Bundonis, H.H. Szu // *Conference Proceedings of SPIE*. — 3391. — 1998. DOI: 10.1117/12.304883.
12. Gao R.X. Continuous Wavelet Transform / R.X. Gao, R Yan // Springer, Boston, MA. — 2011. — N/A. DOI: 10.1007/978-1-4419-1545-0_3.
13. Furht B Discrete Wavelet Transform (DWT) / B Furht // *Encyclopedia of Multimedia*. — 2006. — N/A. DOI: 10.1007/0-387-30038-4_62.
14. Khalid A. Wavelet Analysis and High Quality JPEG2000 Compression Using Daubechies Wavelet / A. Khalid, U. Afsheen, S.U. Baig // *Conference Proceedings of SPIE*. — 8285. — 2011. DOI: 10.1117/12.913401.
15. Cesbron F.C. Wavelet and Fractal Transforms for Image Compression / F.C. Cesbron, F.J. Malassenet // *6th International Conference on Image Processing and its Applications*. — 1997. — N/A. — p. 77 – 80.
16. Jianhua Z. A Novel Algorithm for Threshold Image Denoising Based on Wavelet Construction / Z. Jianhua, Z. Qiang, Z. Jinrong, S. Lin, W. Jilong // *Cluster Computing*. — 22. — 2019. — p. 12443–12450. DOI: 10.1007/s10586-017-1655-0.
17. Zhao M. A Method of Image Feature Extraction Using Wavelet Transforms / M. Zhao, Q. Chai, S. Zhang // *Emerging Intelligent Computing Technology and Applications*. — 5754. — 2009. DOI: 10.1007/978-3-642-04070-2_21.
18. Rai D. Wavelets and their Application in Image Processing with Future Research Prospect / D. Rai, K. Shrivastava // *International Journal of Science and Research*. — 6:12. — 2017. DOI: 10.21275/ART20178102.