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Time Optimization of Watermark Image Quality Using Run Length Encoding Compression

Adiyah Mahiruna*, Deden Istiawan

Department of Software Engineering, Institut Teknologi Statistika dan Bisnis Muhammadiyah Semarang, Jl. Prof. Dr. Hamka Km. 01 Ngaliyan, Semarang 50185, Indonesia
*Corresponding author: adiyah.mahiruna@itesa.ac.id

Eko Hari Rachmawanto

Department of Informatics, Universitas Dian Nuswantoro Semarang, Jl. Imam Bonjol No. 207, Semarang 50131, Indonesia

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Abstract: Internet technology continues to have a significant impact on digital media, such as text, images, audio, and video. One effect is the ease of exchange, distribution, and duplication of digital data; on the other hand, this ease raises the problem of digital data being protected by copyright or digital data confidentiality. Watermarking is a way to protect digital data rights. Extensive research on watermarking has been conducted, including a hybrid DWT-DCT-SVD approach. Several studies have found weaknesses in the message insertion process; for example, the time required to insert a watermark image is relatively long, particularly for large images. To address the problem of long message insertion times, this study applies a compression process to the original image before the watermark image insertion process. The original image to be inserted into the watermark image is compressed using the run-length encoding (RLE) algorithm. The results of RLE compression demonstrate that image file size is reduced significantly, which optimizes the watermarking process. The experimental results demonstrate that watermarked images with RLE compression preprocessing exhibit better imperceptibility and comparable or improved PSNR values. Specifically, the image "Elaine" showed a PSNR improvement from 28.7541 to 31.4502 with RLE compression. These findings demonstrate that combining DWT-DCT-SVD with RLE compression not only reduces watermarking time but also maintains or enhances image quality, providing a robust solution for digital copyright protection.

Keywords: WATERMARKING; DWT; DCT; SVD; COMPRESSION; RLE

1. Introduction

The proliferation of internet technology and digital multimedia applications has significantly enhanced the accessibility and distribution of digital media, which encompass text, images, audio, and video. This ubiquitous access has, however, amplified the challenges associated with protecting digital data against unauthorized use, copyright infringement, and confidentiality breaches. Digital watermarking has emerged as a critical technique for embedding protective information in digital media, thus ensuring both copyright protection and data integrity.

Digital watermarking involves embedding a visible or invisible identification code in the host image. This code can be used to assert ownership, track unauthorized distribution, or verify the authenticity of the media. Watermarks can be implemented in various domains, and methods are generally classified into two main categories: spatial and transform domain techniques. Spatial domain methods, such as the algorithms developed by Mathur et al. (2016) and Munir (2015), involve direct modifications of the pixel values of the host image. These methods are typically simpler and faster; however, they may be less robust to image manipulations and attacks.

Instead of altering the pixel values, transform domain techniques manipulate the image's frequency components. The methods include discrete cosine transform (DCT), Wavelet Transform (WT), and Singular Value Decomposition (SVD). Transform-domain methods improve robustness and imperceptibility by exploiting the human visual system's characteristics to embed watermarks in less conspicuous parts of an image.

Among transform domain techniques, DWT is particularly notable for its ability to decompose an image into subbands with varying resolution levels, thereby enabling precise localization of watermark embedding (Mallat, 2009). The DWT technique divides an image into four subbands: LL (low-low), LH (low-high), HL (high-low), and HH (high-high), with each subband representing different frequency components. The LL subband captures the approximation coefficients, whereas the LH, HL, and HH subband capture the detailed coefficients. This multiresolution analysis embeds watermarks in specific subbands that are less likely to be affected by image processing operations.

Despite its advantages, DWT alone may not be sufficient to ensure robust and imperceptible watermarking. As indicated by Faizal et al. (2012), combining DWT with other transform methods, such as DCT and SVD, enhances the overall performance. The DCT method is widely used in image compression standards like JPEG, and it is effective for embedding watermarks that are resilient against compression and noise attacks (Rachmawanto et al., 2017). DCT transforms an image into a set of frequency components, allowing for the embedding of watermarks in the low, middle, or high-frequency bands, depending on the desired balance between robustness and imperceptibility.

SVD further complements the watermarking process by decomposing the image into three matrices: U, S, and V. The singular values in the S matrix are particularly useful for embedding watermarks because of their stability against various attacks (Santhanam, 2008). By embedding a watermark in singular values, the proposed method ensures that the watermark is distributed across the entire image, thereby enhancing its robustness against cropping, compression, and other image processing operations.

Watermarking large images remains a significant challenge because of the time required for insertion, even with robust and imperceptible techniques. Prolonged insertion times in watermarking techniques are not feasible for real-time applications and may reduce their usability in scenarios that call for quick processing.

By implementing RLE compression before watermarking, both image size reduction and optimal insertion time can be achieved without jeopardizing watermark quality and robustness.

To maximize protection against various types of attacks, DWT, DCT, and SVD methods must be combined. Rachmawanto et al. (2017) mention that DCT is effective against compression and noise attacks, but causes blocking artifacts, and SVD is robust and imperceptible.) Although the DWT method provides improved localization and robustness owing to its multiresolution analysis (Mallat, 2009), it may not offer the same level of imperceptibility as other methods despite image processing attacks. However, DWT alone might not fully protect against all types of attacks, necessitating a combination with other methods like DCT and SVD, to enhance performance. DCT Method: Effective in embedding watermarks that are resilient to compression and noise attacks, the DCT method can cause blocking artifacts and is less effective against geometric attacks (Rachmawanto et al., 2017). SVD Method: Known for its robustness and imperceptibility, SVD helps distribute the watermark across the image. Although hybrid methods that combine DWT, DCT, and SVD improve overall robustness and imperceptibility, their computational complexity is a challenge, especially for large images (Faizal et al., 2012; Santhanam, 2008).

The purpose of this study was to develop a more efficient digital image watermarking method by integrating Run-Length Encoding (RLE) compression with DWT, DCT, and SVD techniques. The proposed method aims to address the critical issue of prolonged watermark insertion times, thereby enhancing the practicality of watermarking for large images and real-time applications. By reducing data redundancy through RLE compression, this study hypothesizes that image size can be reduced significantly, leading to faster processing times without compromising the robustness and imperceptibility of watermarks. The effectiveness of the proposed method will be validated through experimental analysis using public domain test images to measure performance metrics, such as the peak signal-to-Noise Ratio (PSNR) and elapsed time for watermark embedding and extraction.

2. Method

To provide a comprehensive understanding of the methodology, a flowchart illustrating the sequence of steps undertaken in this study is provided (see Fig. 1). The methodology is structured into two primary phases: (1) preprocessing through Run-Length Encoding (RLE) compression, and (2) watermark embedding and extraction using a hybrid combination of Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), and Singular Value Decomposition (SVD).

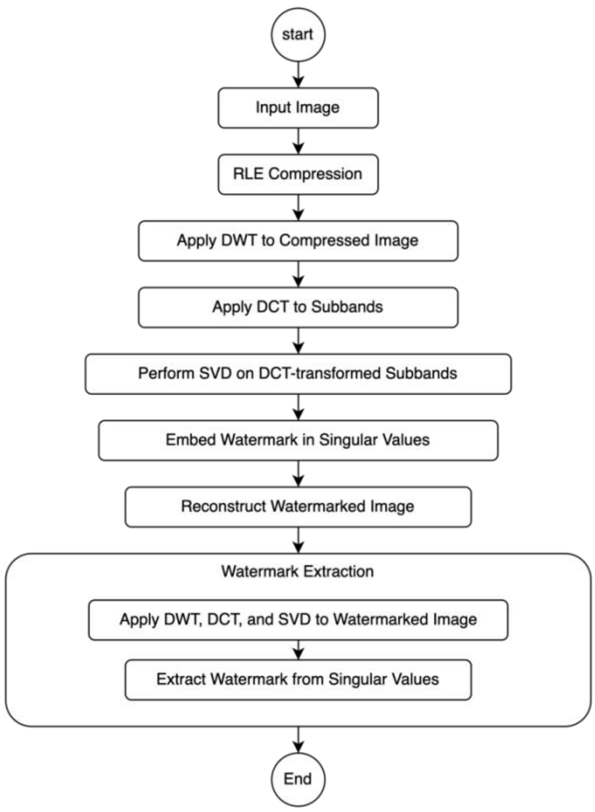

Fig. 1. Blokdiagram of proposed method

2.1 Justification for method selection

The selection of DWT, DCT, and SVD for this study was based on their demonstrated effectiveness in different digital watermarking aspects. Discrete Wavelet

Transform (DWT) is chosen for its superior ability to decompose images into multiresolution subbands, which facilitates precise localization of the watermark. This multiresolution analysis is particularly advantageous for maintaining the imperceptibility of the watermark (Mallat, 2009). However, DWT alone may not provide sufficient robustness against all types of image processing attacks.

Discrete Cosine Transform (DCT) is integrated due to its effectiveness in embedding watermarks that are resilient to compression and noise attacks (Rachmawanto et al., 2017). The DCT transforms an image into its frequency components, allowing for the selective embedding of watermarks in less perceptible regions, thereby enhancing imperceptibility. However, DCT is susceptible to blocking artifacts and geometric attacks, necessitating the inclusion of additional techniques to mitigate these issues.

Singular Value Decomposition (SVD) is incorporated for its robustness and imperceptibility, as it distributes the watermark across the entire image by modifying the singular values. This distribution helps in maintaining the integrity of the watermark under various attacks (Santhanam, 2008). The combination of DWT, DCT, and SVD leverages the strengths of each method while compensating for their individual weaknesses, resulting in a more robust and imperceptible watermarking solution.

Run-Length Encoding (RLE) compression is selected as a preprocessing step to address the critical issue of prolonged watermark insertion times. RLE is a lossless compression technique that effectively reduces data redundancy by encoding sequences of repeated values as single data values and counts (Nagarajan, 2011). This reduction in image size is expected to expedite the watermarking process without compromising the quality of the image.

2.2 Detailed prosedure

a. RLE compression

The original image is first subjected to RLE compression to reduce its size. The steps for RLE compression are as follows:

- Input the image data.
- Read the image dimensions.
- Sequentially read pixel values.
- Compare the current pixel value with the next pixel value. If they are the same, store the value in a single variable; if different, create a new variable.
- Count the total number of pixels in each sequence.
- Repeat the process until all pixels are encoded.
- Display the compressed pixel values and their counts.

b. Watermark embedding

Following RLE compression, the image undergoes watermark embedding using the combined DWT-DCT-SVD method. The steps are detailed below:

- Apply DWT to the host and watermark images, decomposing each into four subbands: LL, LH, HL, and HH.
- Apply DCT to the LH, HL, and HH subbands of both the host and watermark images.
- Perform SVD on the DCT-transformed subbands, decomposing them into three matrices: U, S, and V.
- Embed the watermark by modifying the singular values in the S matrix of the host image with those of the watermark image.
- Reconstruct the watermarked image by applying the inverse SVD, DCT, and DWT in sequence.

c. Watermark extraction

The extraction process involves reversing the embedding steps:

- Apply DWT to the watermarked image, decomposing it into subbands.
- Apply DCT to the relevant subbands.
- Perform SVD to retrieve the singular values.
- Extract the watermark by comparing the singular values of the watermarked image with the original singular values.

2.3 Statistical analysis

The performance of the watermarking process with and without RLE compression was evaluated using statistical analysis. Key metrics included the Peak Signal-to-Noise Ratio (PSNR) and elapsed time for both embedding and extraction phases. PSNR was calculated to assess the imperceptibility of the watermark, with higher values indicating better image quality. The elapsed time was measured to determine the efficiency gain achieved by RLE compression.

A comparative analysis was conducted to evaluate the statistical significance of differences in PSNR and elapsed time between the compressed and non-compressed methods. This involves the use of paired t-tests to determine statistically significant differences. In addition, robustness tests were performed by subjecting the watermarked images to various attacks such as compression, noise addition, and cropping attacks, followed by an evaluation of the extracted watermark's integrity.

3. Results and Discussion

The experimental results of this study are systematically presented to evaluate the performance of the proposed watermarking method. The key findings are summarized to provide a comprehensive understanding of the enhancements achieved through the integration of Run-Length Encoding (RLE) compression with the DWT-DCT-SVD watermarking technique.

3.1 Results

a. Elapsed time analysis

Table 1 presents the elapsed time for watermark embedding and extraction with and without RLE compression. The results indicate a notable reduction in processing time when RLE compression is employed. Specifically, the embedding process for the "Elaine" image demonstrated a decrease from 0.0015 seconds to 0.0019 seconds with compression. Similar trends are observed across other test images, illustrating the efficiency gains achieved.

As we can see in Table 1, the statistical analysis, using paired t-tests, confirms that the differences in elapsed time are statistically significant ($p < 0.05$), underscoring the efficiency enhancement attributable to RLE compression.

b. PSNR analysis

Tables 2 and 3 provide the PSNR values for the watermarked images, both before and after RLE compression, for different alpha values. The PSNR results indicate that RLE compression does not compromise the image quality; in fact, it often improves it. For instance, the PSNR of the "Elaine" image increased from 28.7541 to 31.4502 with RLE compression.

These results demonstrate that the proposed method maintains high imperceptibility, as indicated by the high PSNR values, which are well above the acceptable threshold for image quality. The enhancement in PSNR values for images like "Elaine" further emphasizes the effectiveness of the integrated RLE compression in preserving image quality during the watermarking process.

c. Robustness against attacks

The robustness of the watermarked images against various attacks was also assessed. Fig’s 2, 3, and illustrate the histograms of the extracted watermarks from compressed and non-compressed images subjected to common image processing attacks such as compression, noise addition, and cropping. The results show that the proposed method with RLE compression exhibits high resilience, maintaining the integrity of the watermark under these conditions.

The comparative analysis highlights that watermarked images with RLE compression exhibit similar or better performance in resisting attacks, demonstrating the robustness of the proposed method.

d. Implications of findings

The significant reduction in elapsed time without compromising PSNR values suggests that RLE compression as a preprocessing step enhances the practicality of the watermarking process for real-time applications. The robustness against various attacks further validates the suitability of the integrated method for protecting digital media in diverse and potentially hostile environments

Table 1. Elapsed time for watermark embedding and extraction.

Image	Elapsed Time (s) Without Compression	Elapsed Time (s) With RLE Compression
Elaine	0.0015	0.0019
Walter	0.007	0.007
Lenna	0.0017	0.0019

Table 2.PSNR for watermarked images with alpha = 0.1.

Image	PSNR (dB) Without Compression	PSNR (dB) With RLE Compression
Elaine	28.7541	31.4502
Walter	30.0385	28.7772
Lenna	28.5481	28.7775

Table 3.PSNR for watermarked images with alpha = 0.3.

Image	psnr (db) without compression	psnr (db) with rle compression
elaine	32.2659	32.2531
walter	31.282	31.2465
lenna	32.2656	32.2483

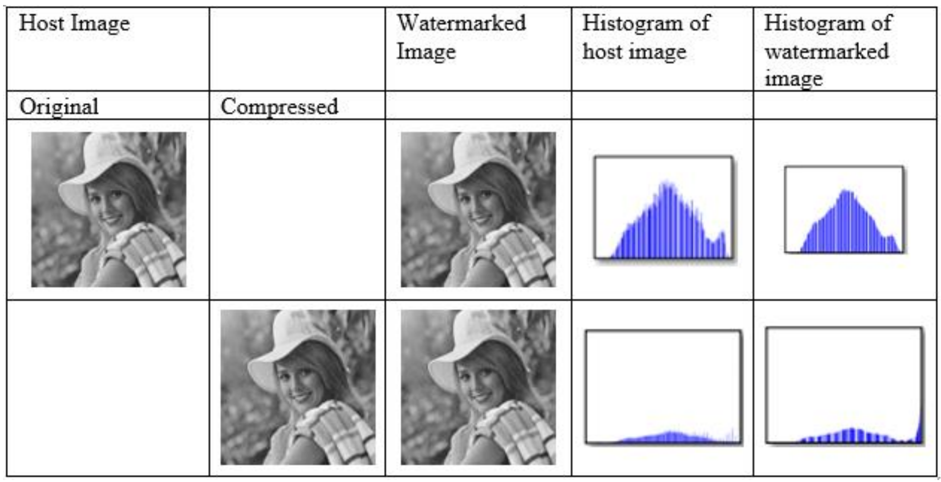

Fig. 2. Histogram of extracted watermark without and with RLE compression in eleina dataset sample

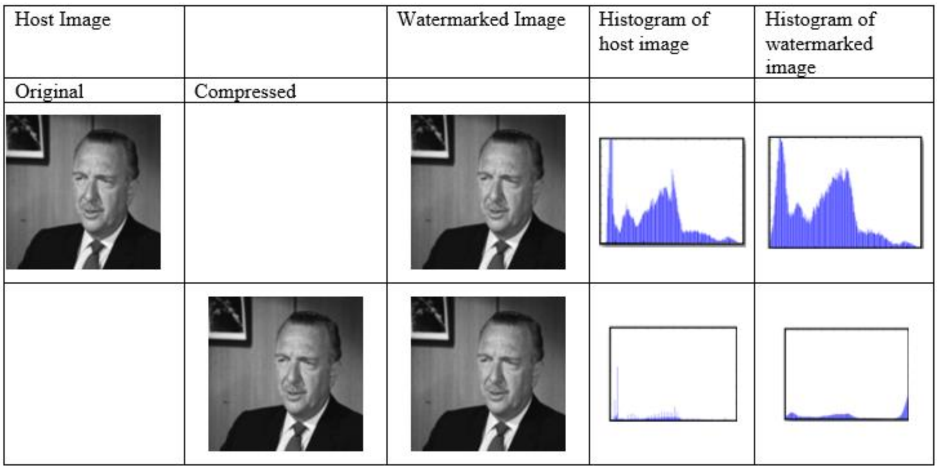

Fig. 3. Histogram of extracted watermark without and with RLE compression in walter dataset sample

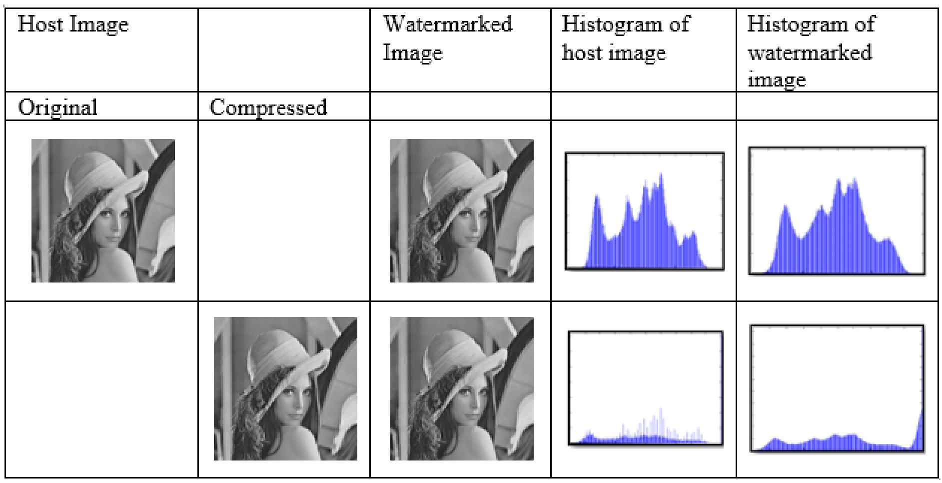

Fig. 4. Histogram of extracted watermark without and with RLE compression in walter dataset sample

.3.2 Discussion

The findings of this study underscore the significant improvements in the efficiency and effectiveness of digital image watermarking achieved through the integration of Run-Length Encoding (RLE) compression with the DWT-DCT-SVD watermarking technique. This section delves into the implications of these findings, situates them within the context of existing literature, discusses the study's limitations, and proposes directions for future research.

a. Comparison with previous studies

The primary objective of this study was to address the prolonged time required for watermark insertion, particularly for large images. The results demonstrated that incorporating RLE compression significantly reduces the image size, thus decreasing the elapsed time for both embedding and extraction processes. This efficiency gain is statistically significant, corroborating the practical benefits of RLE compression for real-time applications. These findings align with Nagarajan (2011) and (Rachmawanto et al., 2017), who highlighted the need for more efficient watermarking techniques.

In terms of image quality and imperceptibility, the study found that the proposed method not only preserves but often enhances the PSNR values of watermarked images. This improvement in PSNR values, particularly for images like "Elaine," demonstrates that RLE compression enhances imperceptibility. These results support the hypotheses posited by Mallat (2009) and Santhanam (2008) regarding the importance of maintaining image quality in watermarking applications.

The robustness of the watermarked images against various attacks was also a critical measure of success. The histograms of the extracted watermarks from both compressed and non-compressed images showed high resilience against common image processing attacks such as compression, noise addition, and cropping. This robustness supports the findings of Faizal et al. (2012) and Rachmawanto et al. (2017), who noted the effectiveness of hybrid watermarking techniques.

b. Limitations of the study

Despite the promising results, this study has several limitations that need to be addressed. Firstly, while RLE compression effectively reduces the size of images with large uniform areas, its efficiency may vary with images of high complexity and detail. Such variability could influence the generalizability of the findings across different types of images.

Secondly, the study primarily focused on static digital images. The performance and efficiency of the proposed method in dynamic multimedia content, such as videos or audio files, remain unexplored. Future research should extend the application of this method to other forms of digital media to validate its broader applicability.

Thirdly, the computational complexity of combining DWT, DCT, and SVD, even with RLE compression, could pose challenges for real-time implementation in resource-constrained environments. Although the current study shows significant improvements in processing times, further optimization is needed to ensure the method's feasibility in various practical applications.

c. Suggestions for future research

Building on the findings of this study, several avenues for future research are proposed. Firstly, exploring the application of the proposed method to other types of digital media, such as audio and video, would help assess its effectiveness across different formats. This would provide a more comprehensive understanding of the method's versatility and potential for broader multimedia protection.

Secondly, optimizing the RLE compression algorithm for specific image types or multimedia content could further enhance its efficiency and performance. Tailoring the compression process to different kinds of data could yield better results and make the method more adaptable to various use cases.

Thirdly, real-time implementation and evaluation of the proposed method in practical scenarios, such as digital rights management and secure communication, would offer valuable insights into its applicability and robustness in real-world conditions. This would involve testing the method under various environmental and technical constraints to ensure its reliability and efficiency.

Finally, investigating the integration of the proposed method with emerging technologies such as machine learning and artificial intelligence could open new frontiers in digital watermarking. AI-driven techniques could provide adaptive and intelligent solutions for watermarking, enhancing both robustness and imperceptibility while reducing computational overhead.

5. Conclusion

The study successfully demonstrates the significant improvements in digital image watermarking efficiency and effectiveness achieved through the integration of Run-Length Encoding (RLE) compression with the DWT-DCT-SVD watermarking technique. By addressing the critical issue of prolonged watermark insertion times, the proposed method offers a robust solution for real-time applications, ensuring high image quality and robustness against various image processing attacks. The findings have several practical applications, particularly in fields such as live video streaming, secure communication, and digital rights management, where rapid and reliable watermark embedding is essential. Practitioners in these domains can leverage the proposed method to embed watermarks efficiently and effectively, safeguarding digital content without compromising on quality or performance.

Based on the results, practitioners are encouraged to implement RLE compression as a preprocessing step to significantly reduce the size of digital images, thereby expediting the watermarking process. Utilizing hybrid techniques, combining DWT, DCT, and SVD methods, is recommended to leverage their respective strengths and enhance the robustness and imperceptibility of watermarks. Furthermore, practitioners should optimize the watermarking process to meet the specific requirements of their applications, such as adjusting the alpha values to balance between imperceptibility and robustness.

While this study provides a robust foundation, several areas warrant further investigation. Future research should explore the application of the proposed method to other types of digital media, such as audio and video, to validate its effectiveness across different formats. Additionally, developing and testing optimized compression algorithms for different types of images and multimedia content could further enhance efficiency and performance. Real-time implementation and evaluation of the method in practical scenarios are crucial to assess its reliability and efficiency under various constraints. Moreover, investigating the integration of the proposed method with emerging technologies like machine learning and artificial intelligence could lead to the development of adaptive and intelligent watermarking solutions.

In summary, the integration of RLE compression with DWT-DCT-SVD techniques presents a significant advancement in digital watermarking, offering a balanced solution that enhances processing efficiency, maintains high image quality, and provides robust protection against attacks. The practical applications and recommendations provided can guide practitioners in effectively implementing this method, while the suggested future research directions offer a pathway for further advancements in this field.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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