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Ir and visible image fusion using DWT and bilateral filter

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ABSTRACT

Image fusion combines images from different sensors into a more descriptive image Infrared (IR) and visible (VI) image fusion has significant applications in surveillance, medical imaging, and target detection, where complementary information enhances scene comprehension This work proposes a novel fusion technique with Discrete Wavelet Transform (DWT) and a Bilateral Filter (BF), termed DWTBF The algorithm separates images into frequency sub-bands with the help of DWT, marking fine details and structural content

Low-frequency sub-bands are mixed with the help of averaging for the sake of preserving coherence of the scene and high frequency sub-bands made up of edges and texture are mixed with the help of weighted average High-frequency components are processed with a bilateral filter to preserve edges and reduce noise and artifacts The new method outperforms conventional methods in preserving scene details from VI images and enhancing object visibility from IR images

Keywords: *Image Fusion, Discrete Wavelet Transform (DWT), Bilateral Filter, Infrared and Visible Fusion, Multiresolution Analysis, Edge Preservation, Image Processing.*

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Introduction

Image fusion is a method that combines complementary information from several images to generate a single image with increased interpretability and uses in areas such as surveillance, medical imaging, and remote sensing. Infrared (IR) imaging detects thermal radiation, allowing the observation of objects under low-light or

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obscured environments, whereas visible (VI) imaging delivers high-resolution spatial information in ordinary lighting. Merging IR and VI images takes advantage of the strengths of both modalities and produces images with rich information content.

e.g., the Discrete Wavelet Transform (DWT), break down images into several frequency components, making it easier to fuse prominent features. The DWT provides multiresolution analysis, enabling the decomposition of image details at various scales. But DWT by itself may not be efficient in preserving edges and can lead to artifacts. To overcome these issues, the combination of DWT with edge-preserving filters like the Bilateral Filter (BF) has been suggested. The BF filters images while keeping edges intact by taking into account both spatial neighborhood and intensity differences.

This work introduces a fusion technique that unites DWT and BF for improving the quality of fused IR and VI images. The suggested method includes pre-processing the images to a standard resolution, using BF to suppress noise without degrading edges, transforming the images into frequency sub-bands by DWT, and using certain fusion techniques for low- and high-frequency components. The resulting fused image is obtained by inverse DWT. Performance is measured by quantitative measures like

Structural Similarity Index (SSIM), Edge-Based Similarity Index ($Q^{AB/F}$), and Sum of Correlation Differences (SCD), proving the efficacy of the proposed method in maintaining edge details, minimizing artifacts, and maximizing image contrast against current methods.

Problem Statement

Traditional image fusion methods, such as direct pixel averaging and basic spatial domain methods, often fail to properly combine thermal (infrared) and visible light images without losing their critical details. Pixel averaging can lead to blurriness and the loss of important features, thereby making it difficult to extract useful information from the resulting fused image. In addition, many existing fusion methods introduce artifacts and distortions, thereby degrading image quality and reducing the effectiveness of applications like surveillance, medical imaging, and target detection. These methods face difficulties in maintaining the balance between structural information from visible images and thermal contrast from infrared images, leading to images that suffer from shortcomings in clarity and detail enhancement.

Besides quality constraints, computational efficiency is a major challenge, particularly in real-time applications. The majority of conventional fusion algorithms require intensive processing time and resources, rendering them inappropriate for applications with fast decision making, such as autonomous navigation, military reconnaissance, and real time diagnostics. Additionally, most existing methods are incapable of adjusting to varying environmental conditions, resulting in unstable outputs. To overcome these challenges, there is an urgent need for a high quality, robust fusion method that can efficiently combine infrared and visible images with structural integrity, reduced artifacts, and improved contrast, while achieving a balance between computational speed and overall performance.

Methodology

The process of fusion is a systematic pipeline:

I. **Preprocessing:** Ensures uniformity in IR and VI images by adjusting their dimensions to a consistent scale, thereby facilitating alignment.

II. **DWT Decomposition:** Splits images into low-frequency (LL) and high frequency (LH, HL, HH) sub-bands to enable effective fusion.

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III. Fusion Strategy:

- LL sub-bands are averaged with an averaging technique to preserve overall structure.
- LH, HL, HH high-frequency sub-bands are processed with a weighted fusion method in order to preserve edge and texture information.
- Bilateral Filtering (BF) is used for removing noise without affecting the sharp edges.

IV. Reconstruction: The combined image is reconstructed with the help of Inverse DWT (IDWT)to produce a final enhanced image. **V. Development and Implementation:**

The suggested algorithm is implemented on MATLAB, using image processing libraries for DWT decomposition and bilateral filtering. The method of fusion is tested on standard infrared and visible image datasets, with comparisons to existing methods used to assess effectiveness.

VI. Performance Analysis: The quality of fusion is determined by quantitative and qualitative assessments

- Numerical Indicators:
- Structural Similarity Index (SSIM): Quantifies structural integrity and clearness of an image.
- Sum of Correlation Differences (SCD): Assesses feature retention and sharpness.
- Edge-Based Similarity Index ($Q^{AB/F}$): Captures edge quality preservation.
- Noise and Artifact-Based Fusion ($N^{AB/F}$): Estimates distortion suppression.
- Qualitative Analysis: Visual evaluation checks the distinctness, contrast, and maintenance of features in combined images.

VII. Results and Analysis: Experimental findings reveal that the DWTBF method performs better than conventional fusion techniques in retaining delicate details, enhancing contrast, and reducing noise. The fused images yielded have better object visibility, enhanced clarity, and enhanced structure preservation, hence proving the efficiency of the proposed method.

VIII. Conclusion and Future Directions: The DWTBF-based fusion technique performs very effectively to enhance image fusion by preserving edge sharpness, minimizing artifacts, and maximizing contrast. The technique is extremely effective for surveillance, medical imaging, remote sensing, and military uses. But for:

- Adaptive filtering methods for detail improvement in low-contrast images.
- Integration of deep learning model for intelligent feature selection.
- Optimization of real-time processing to enable usage in high-speed applications.

IX. Documentation and Presentation: The project report comprehensively covers the methodology, implementation, and performance analysis, incorporating numerical comparisons and graphical outcomes. The findings are presented in tabular form in a PowerPoint presentation, which comprises:

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- Project Overview and Objectives
- Suggested Fusion Technique
- Experimental Results and Comparisons
- Conclusion and Future Research Directions

The report is organized to offer a correct and comprehensive description of the fusion process, hence ensuring the methodology is reproducible and comprehensible to researchers and practitioners. Formulation guarantees efficient communication of central concepts, which can be used to discuss and further refine.

Simulation and Results

Simulation

The images below are obtained by MATLAB tools.

To analyze the performance of DWTBF, its outputs were compared against three state-of-the-art fusion algorithms:

I. ISR with Saliency Detection (ISRSD)

II. Gradient Transfer Fusion (GTF)

III. Convolutional Sparse Representation (CSR)

All these techniques were compared using publicly available TWO image fusion datasets, i.e., Kaptein, Two-Person Image. Sand Path and UN Camp. The results evidently indicated that DWTBF outperformed other techniques consistently with sharper, higher-contrast fused images and better detail preservation.

The research approach for the subjective evaluation of picture fusion presented in Figures 6.1,6.2,6.3 and 6.4, in which four image pairs of the TNO dataset, taken in various scenarios were assistance visual is employed. Each figure presents the performance of various methods, apart from the methodology we have conceived to employ. The differences in visuals between the current and proposed methods are clear and are shown through both visual and performance measurements to be the most effective such technique details and the contrast. The method suggested thrives in enhancing the contrast of the VI image to life while simultaneously enhancing the fine details which lead to a high-quality fusion.

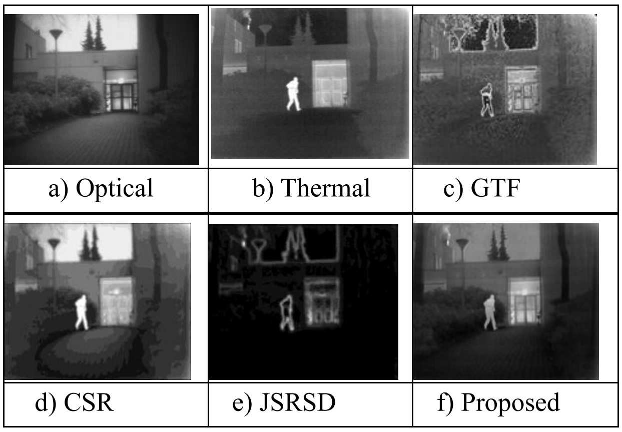

Figure: Outputs of Kaptein Image

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Figure shows the "Kaptein" image, while Figures 6.1a and 6.1b are the Optical and Thermal images. The target is easily visible in the image, but not at all in the VI image. Figures 6.1c-e do not entirely contain the information of the clay target and they do not present the complementary information of the two modalities. Contrarily, Figure 6.1f, which is the output of the proposed algorithm, being a combination of the optimal features of both images, the composite view of the scene is therefore quite close and precise.

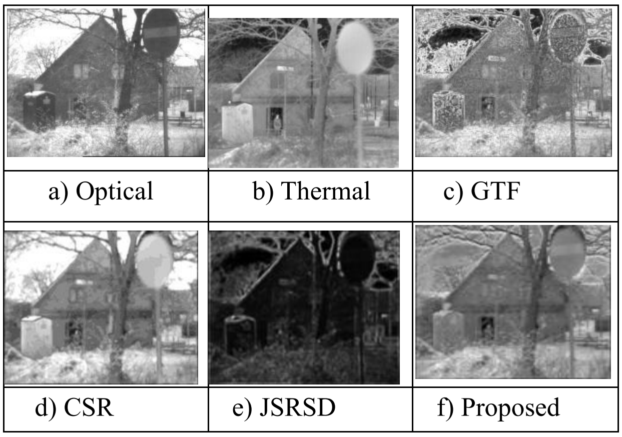

Figure: Outputs of Two-Person Image

Figure shows an image that has two individuals. The fused image achieved by the method suggested by the proposed method is certainly more colorful and descriptive in comparison to Figures 6.2c-e that do not retain the important target details and the contrast. The proposed method succeeds in enhancing the contrast of the Optical image to life while concurrently enhancing the fine details which lead to a high-quality fusion.

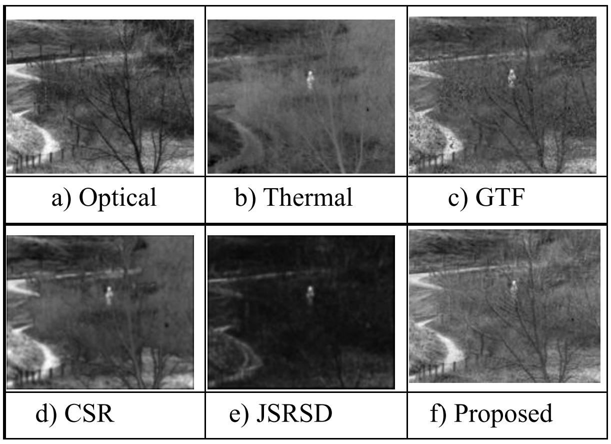

Figure: Outputs of Sand Path Image

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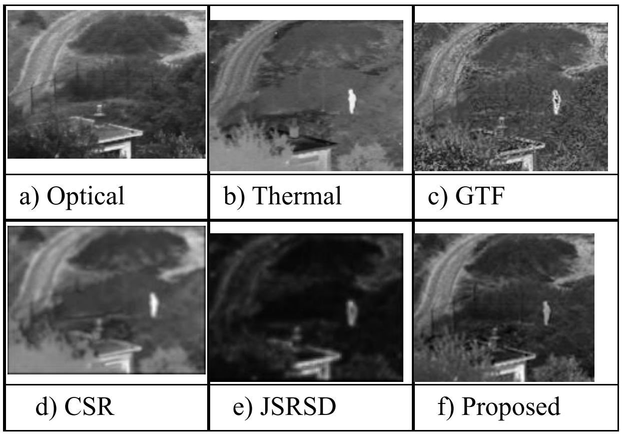

Figure: Outputs of UN Camp Image

From the "UN Camp" figure in Figure, the segments (a) - (f) are described as follows: (a) is the Thermal (IR) image, (b) represents the Optical (VI) image, (c) is represented as JSRSD, (d) to GTF, (e) to CSR, (f) to the image generated by us, that is, the one to see the fused image. The "Sand Path" and "UN Camp" scenes on the Figures ashowing the intentional but subtle transfer of the target individual's patterns in the calculated blend are critical. Image sharpening and artifact removal are the most important operations for target spotting in an appropriate manner. As per the visual observations, the suggested approach does enhance the contrast in a highly effective manner and simultaneously, the background features are also retained in detail. Fuzziness and distortions are, however, reduced to a minimum

Tables 6.1,6.2,6.3, and 6.4 show different qualitative parameters used to measure the performance of a series of algorithms for different sets of images. Table 6.1 offers $Q^{AB/F}$scores for four images, Table 6.2 offers SCD scores, Table 6.3 shows SSIM scores and Table 4 shows qualitative judgment based on $N^{AB/F}$i.e., "UN Camp," "Sand Path," "Two-Person Image," "Kaptein."

Referring to the values from Tables 6.1,6. 2, 6.3, and 6.4, it can be seen that the proposed technique produces better values for all parameters. This supports the fact that the proposed algorithm provides better performance through enhanced contrast and brightness. The results also show that the technique preserves edge details properly when reducing distortion and artifacts. Overall, the results show that the proposed technique performs better than the three state-of-the-art techniques.

Table: Performance measure—$Q^{AB/F}$:

Image	Algorithms			
	GTF	CSR	JSRSD	Proposed
Two-person	0.5779	0.5930	0.2484	0.6122
Kaptein	0.3737	0.3781	0.1160	0.3926
UN camp	0.3850	0.3883	0.1620	0.4106
Sand Path	0.3238	0.3253	0.1287	0.3469

Table: Comparison of methods SCD:

Image	Algorithms			
	GTF	CSR	JSRSD	Proposed
Two-person	1.2530	1.4146	1.1247	1.7021
Kaptein	0.9241	1.5406	0.8383	1.6610
UN camp	1.0380	1.4292	0.8837	1.4794
Sand Path	1.2591	1.4980	1.1550	1.6485

Table: Comparison of methods SSIM(a)

Image	Algorithms			
	GTF	CSR	JSRSD	Proposed
Two-person	0.9594	0.9720	0.9254	0.9702
Kaptein	0.9879	0.9851	0.9822	0.9865
UN camp	0.9885	0.9847	0.9819	0.9858
Sand Path	0.9934	0.9920	0.9915	0.9930

Table: Comparison of methods $-N^{AB/F}$

Image	Algorithms			
	GTF	CSR	JSRSD	Proposed
Two-person	0.2604	0.2901	0.7895	0.2598
Kaptein	0.2280	0.2543	0.5072	0.2276
UN camp	0.1657	0.1871	0.5008	0.1655
Sand Path	0.1631	0.2104	0.4486	0.1623

Conclusion

The suggested DWTBF (Discrete Wavelet Transform & Bilateral Filter) image fusion method effectively merges infrared (IR) and visible (VI) images, thus improving structural preservation, contrast, and noise elimination.

Through image decomposition into multiple frequency sub-bands using DWT, the method allows the selective merging of low- and high-frequency sub-bands, thus preserving key details. Bilateral Filtering (BF) application also improves the high-frequency sub-bands through denoising without compromising edge sharpness, thus producing a more aesthetically pleasing and informative fused image. The method outperforms traditional pixel based and transform-based methods, which are often characterized by blurring, artifacts, and loss of essential details.

The performance assessment using the SSIM, $Q^{AB/F}$, $N^{AB/F}$, and SCD metrics verifies the benefits of this method over the conventional approach. The results validate that the DWTBF fusion method produces images with improved contrast, improved edge preservation, and minimum distortion, thus making it particularly suitable for application in surveillance, medical imaging, remote sensing, and military vision systems. The fusion method ensures object clarity under varying illumination, thus significantly improving the efficiency of object detection and feature extraction under unfavorable conditions.

While the technique has its merits, it suffers from some limitations, including an average computational complexity, which can restrict its use in practical real-time applications. Optimization techniques, as well as hardware optimization, must be given priority in future studies to enhance processing speed for practical use. In addition, integration of deep learning based adaptive filtering can greatly improve the robustness and adaptability of the fusion technique. Overall, DWTBF is a strong, efficient, and effective image fusion technique that can be further developed for direct use in mission-critical imaging applications.

The DWTBF-based image fusion method has yielded noticeable edge preservation, contrast improvement, and noise removal. To further improve it for easier direct application to real-world scenarios, the future can include the optimization of computational efficiency towards real-time processing. With parallel processing methods, GPU acceleration, or FPGA-based designs, it is feasible to minimize the processing time considerably, and it could become feasible for time-critical applications such as autonomous vehicles, military reconnaissance, and real-time imaging in medicine.

Another area of research with potential is applying deep learning and artificial intelligence (AI) methods in the process of fusion. Convolutional Neural Networks (CNNs) and Generative Adversarial Networks (GANs) can be employed to find the best fusion rules to support adaptive and intelligent fusion processes in dynamic environments. These AI-driven models can enhance feature extraction, noise removal, and adaptive contrast enhancement, further enhancing the quality of fused images.

Besides, the method can be applied to multi-sensor and hyperspectral image fusion, where various imaging modalities like LiDAR, thermal, and Xray can be fused for better scene understanding. Adaptive hybrid fusion techniques, integrating wavelet-based and data-driven techniques to maximize fusion quality across a wide range of application domains, can be investigated in preliminary research. Eventually, such developments will render DWTBF-based fusion more robust, scalable, and applicable in a wide range of applications like smart surveillance, medical diagnosis, robotics, and remote sensing

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