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Optimizing H.264 Intra Prediction: Leveraging Cross Entropy and Error Entropy-based RDO Techniques

Vanila Sildas, Premanand Venkatesh Chandramani, Srinivasan Raj, Rathinam A

Assistant Professor, Department of Electrical and Electronics Engineering, SRM Valliammai Engineering College,
Tamil Nadu, India

Department of Electrical and Electronics Engineering, Sri Sivasubramaniya Nadar College of Engineering,
Tamil Nadu, India

Professor, Department of Information Technology, Sri Sivasubramaniya Nadar College of Engineering,
Tamil Nadu, India

Professor, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology,
Tamil Nadu, India

ABSTRACT: This article explores the implementation and comparative analysis of two advanced intra prediction algorithms for H.264 video encoding: the Cross Entropy-based Intra Prediction Algorithm and the Error Entropy-based Rate-Distortion Optimization (RDO) Intra Prediction Algorithm. Both algorithms aim to optimize the selection of prediction modes for 4x4 macroblocks, enhancing compression efficiency and maintaining image quality. The Cross Entropy-based algorithm focuses on minimizing cross-entropy loss between the original and predicted macroblocks, while the Error Entropy-based RDO algorithm calculates distortion using error entropy and combines it with rate calculations to determine the optimal mode based on RD cost. The effectiveness of these algorithms is demonstrated through detailed mode selection analysis, highlighting their potential to improve video encoding performance.

KEYWORDS: Compression, Intra Prediction, Cross Entropy, Error Entropy.

I. INTRODUCTION

H.264, also known as Advanced Video Coding (AVC), stands as a cornerstone in the domain of video compression standards. Revered for its ability to efficiently compress video data while maintaining high-quality output, H.264 has become a pivotal technology in various multimedia applications, spanning from video streaming to broadcasting and beyond. In the intricate process of video compression, intra prediction emerges as a critical technique within the H.264 framework. This method involves predicting pixel values within a frame based on neighbouring pixels, effectively reducing redundancy and enhancing compression efficiency. By leveraging spatial correlations between adjacent pixels, intra prediction significantly contributes to the overall compression performance of H.264[1].

The intra prediction process includes the luma intra-prediction for a 4x4 block, the chroma intra-prediction for an 8x8 block, and the luma intra-prediction for a 16x16 block [2]. The nine-mode intra-prediction algorithm is pivotal for intra-frame coding in video compression, utilizing various prediction modes to estimate pixel values within a macroblock and thereby enhancing encoding efficiency. The modes include Horizontal (H), which predicts pixel values by using neighbouring pixels in the same row, and Vertical (V), which does so using neighbouring pixels in the same column. The DC mode averages the values of neighbouring pixels both horizontally and vertically, providing a general approach that works well in the absence of strong directional patterns. Diagonal Down Left (DDL) and Diagonal Down Right (DDR) modes use diagonal patterns from top-right to bottom-left and top-left to bottom-right, respectively, catering to specific diagonal patterns in the image. Vertical Right (VR), Horizontal Down (HD), Vertical Left (VL), and Horizontal Up (HU) modes predict pixel values by considering both vertical and horizontal neighbouring pixels,

combining these directions to handle more complex and detailed patterns. These prediction modes are integral to intra-frame coding in video compression, enabling efficient encoding by reducing redundancies within video frames [3].

This algorithm is suitable for hardware realization. Rate distortion (RD) optimization is used in the encoder to determine the coding modes with the minimum RD cost, which helps in deciding which modes to skip and which to select. This mode skip scheme has been reported to achieve a reduction in encoding time of up to 60%. [4]. A rate predictor-based RDO and the sum of absolute integer-transformed difference (SAITD) or the sum of absolute transform difference (SATD) are used for intra 4x4 mode decision, utilizing linear transforms to enhance the cost function by reducing the number of additions and shift operations. [5]. [6] suggested an energy-efficient SAD criteria-based motion estimation method that dynamically modifies the input video in accordance with its quality requirement for H.264 intra-frame encoding.

Chen et al. [7] created an efficient architecture and quality-adjustable method for video encoding. This work offered an effective approach to maintain high throughput rates, low power consumption, and flexible quality adjustments within the suggested architecture.

Within the realm of intra prediction, innovative approaches such as Error Entropy-based and Cross Entropy-based techniques have garnered attention for their ability to further optimize compression efficiency and image quality. These techniques are utilized to choose the best mode during the intra prediction process, ensuring that the selected mode yields the most accurate representation of the original data. The Error Entropy-based method operates by calculating error entropy, which measures the uncertainty or randomness in prediction errors between the original and predicted pixel values. This approach offers a nuanced understanding of distortion within the prediction process, leading to more informed mode decisions and improved compression performance.

Conversely, the Cross Entropy-based technique adopts a different strategy, focusing on minimizing cross-entropy loss between the original and predicted macroblocks. By quantifying the discrepancy between predicted and actual pixel values, this method facilitates the selection of prediction modes that yield the most accurate representations of the original data. As a result, Cross Entropy-based intra prediction not only enhances compression efficiency but also preserves image quality to a significant extent. Both Error Entropy-based and Cross Entropy-based approaches present unique advantages within the realm of intra prediction. Error Entropy offers a comprehensive understanding of distortion patterns, enabling nuanced mode decisions and ultimately leading to improved compression performance. On the other hand, Cross Entropy prioritizes accuracy in pixel prediction, ensuring that selected modes closely resemble the original data, thereby enhancing image fidelity. Together, these innovative techniques contribute to the ongoing evolution of H.264, promising even greater efficiency and quality in video compression applications. The rest of the work is divided into the following sections: The contributions, methodology and implementation of the proposed work are presented in Section 2, the Results are presented in section 3, and the conclusion is presented in Section 4.

II. RELATED WORK

The concept of image inpainting was first introduced by Bertamio et al. [1]. The method was inspired by the real inpainting process of artists. The image smoothness information interpolated by the image Laplacian is propagated along the isophotes directions, which are estimated by the gradient of image rotated by 90 degrees.

Exemplar Based method proposed by Criminisi et al. [2] used a best exemplar patch to propagate target patch including missing pixels. This technique uses an approach which combine structure propagation with texture synthesis and hence produced very good results. In [3], the authors decompose the image into sum of two functions and then reconstruct each function separately with structure and texture filling-in algorithms. Morphological technique is used to extract text from the images presented in [4]. In [5], the inpainting technique is combined with the techniques of finding text in images and a simple algorithm that links them. The technique is insensitive to noise, skew and text orientation. The authors in [6] have applied the CCL (connected component labelling) to detect the text and fast marching algorithm is used for Inpainting.

The work in this paper is divided in two stages. 1) Text- Detection 2) Inpainting. Text detection is done by applying morphological open-close and close-open filters and combines the images. Thereafter, gradient is applied to detect the edges followed by thresholding and morphological dilation, erosion operation. Then, connected component labelling is

performed to label each object separately. Finally, the set of selection criteria is applied to filter out non text regions. After text detection, text inpainting is accomplished by using exemplar based Inpainting algorithm.

III. METHODOLOGY

3.1 Cross Entropy-Based Intra Prediction Algorithm

In the Cross Entropy-based algorithm, the primary focus lies in the calculation of cross-entropy loss for each predicted 4x4 macroblock. This loss is determined by comparing the pixel values of the original macroblock with those predicted by the algorithm. Subsequently, the mode with the minimum loss is selected, thereby optimizing the compression process.

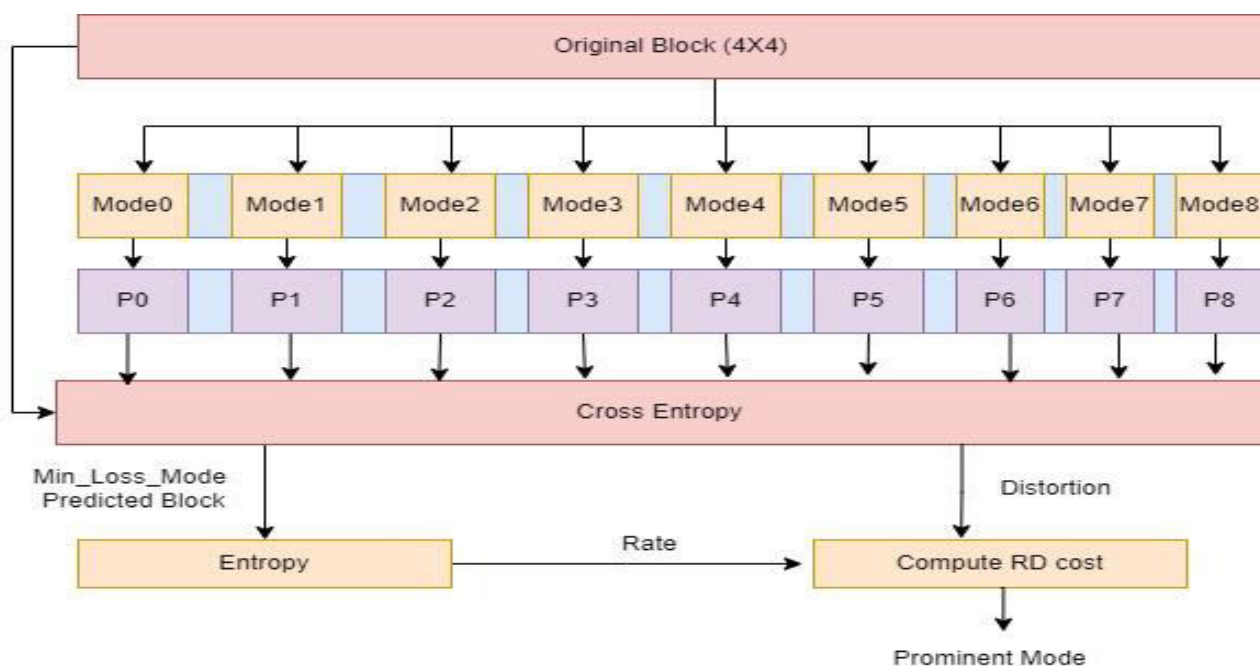


Fig 1: Cross Entropy-based Mode Decision Algorithm Block Diagram

In the proposed technique, the intra prediction process is enhanced by incorporating cross-entropy calculations to evaluate the quality of different predicted macroblocks. Specifically, for a 4x4 macroblock, cross-entropy is computed between the original macroblock and each of the nine predicted 4x4 macroblocks denoted as P₀, P₁, P₂, P₃, P₄, P₅, P₆, P₇, P₈. The goal of this technique is to select the prediction mode that results in the minimum loss value, thereby achieving the most accurate representation of the original data and improving overall compression efficiency.

The cross-entropy loss between the original block and each predicted block is calculated using the following equation.

$$\text{Loss} = - \sum_{i=0}^{15} O(x_i) \times \log P(x_i) \tag{eqn(1)}$$

In this equation, (x_i) represents the original pixel values, while P(x_i) represents the predicted pixel values for each mode. The loss function quantifies the discrepancy between the original and predicted macroblocks, where a lower loss indicates a better prediction match. To determine the optimal prediction mode, the loss values for each of the nine modes are computed. Specifically, these loss values are denoted as Loss₀ to Loss₈, corresponding to the nine different prediction modes. Once these losses are calculated, the minimum loss value (Loss_{min}) is found using the following equation.

$$Loss_{min} = \min(Loss_0, Loss_1, Loss_2, Loss_3, Loss_4, Loss_5, Loss_6, Loss_7, Loss_8) \quad eqn(2)$$

This equation identifies the mode that has the least cross-entropy loss, and hence the one that most accurately represents the original macroblock. The selected mode, corresponding to the lowest $Loss_{min}$, is then used for intra-frame prediction, ensuring that the chosen mode delivers the best possible prediction accuracy. To illustrate the effectiveness of this method, a graph is drawn for all frames based on the $Loss_{min}$ values, as shown in Figure 1. This figure visually represents the comparative performance of the different prediction modes across frames, demonstrating the technique's ability to achieve high compression efficiency and image quality this approach leverages cross-entropy to not only quantify the prediction error but also to optimize mode selection in the intra prediction process. By focusing on minimizing the loss function, the proposed technique enhances the performance of H.264 video compression, leading to more efficient encoding processes and improved image fidelity.

3.2 Error Entropy-Based RDO Intra Prediction Algorithm

In contrast, the Error Entropy-based RDO algorithm adopts a distinct approach by incorporating error and distortion calculations into its process. The algorithm computes the error for each pixel by contrasting the original and predicted pixel values, subsequently employing entropy-based distortion calculations. Additionally, rate calculations are carried out for the most frequently selected mode, culminating in the determination of the RD cost.

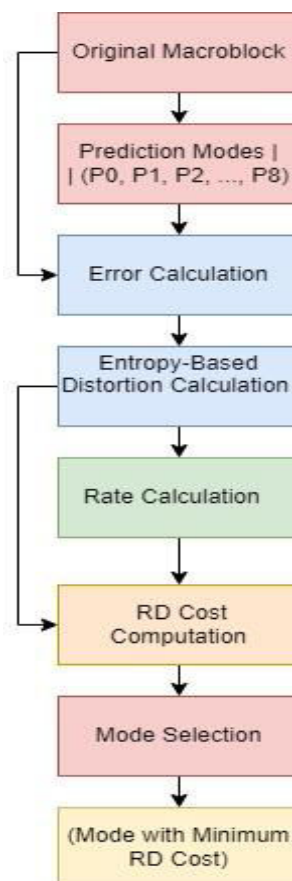


Fig 2: Error-Entropy- RDO-based Mode Decision Algorithm Block Diagram

In this proposed technique, the Error-Entropy-RDO-based Mode Decision Algorithm operates by computing the error-entropy-based distortion value between the original 4x4 macroblock and each of the predicted 4x4 macroblocks (P0 to P8). Subsequently, the predicted 4x4 macroblock with the minimum error-entropy-based distortion value is identified as the prominent mode. This selection process ensures that the predicted mode with the minimum loss function is

chosen as the best mode based on the Predicted Macroblock. The proposed Error Entropy algorithm block diagram is depicted in Figure 2.

$$\text{Error}(x_i) = O(x_i) - P(x_i) \tag{eqn(3)}$$

The error for the predicted blocks is calculated and then the entropy is calculated for the error block using equation 3.

$$D_i = - \sum_{i=0}^{15} \text{Error}(x_i) \times \log \text{Error}(x_i) \tag{eqn(4)}$$

Using the above equation, Distortion value is calculated between the original block and the predicted nine blocks After calculating D_0 to D_8 , the D_{\min} is calculated using equation 5.

$$D_{\min} = \min(D_0, D_1, D_2, D_3, D_4, D_5, D_6, D_7, D_8) \tag{eqn(5)}$$

To calculate the rate for error entropy based RDO technique, the most hit ratio mode in distortion is chosen first .and then the selected predicted block's rate is calculated using equation 6 and 7.

$$R_{\text{selected}} = - \sum_{i=0}^{15} P_{\text{selected}}(x_i) \times \log P_{\text{selected}}(x_i) \tag{eqn(6)}$$

$$\text{RD cost} = D_{\min} + \lambda \cdot R_{\text{selected}} \tag{eqn(7)}$$

IV. EXPERIMENTAL RESULTS

When implemented, the Cross Entropy-based algorithm delivered significant results. It reached an optimal compression ratio of 5.33 during the iteration focused on maximizing compression efficiency, although this resulted in a higher Mean Squared Error (MSE). Conversely, by aiming for the best MSE, the algorithm achieved a reduced MSE of 860.77, but the compression ratio was more moderate.

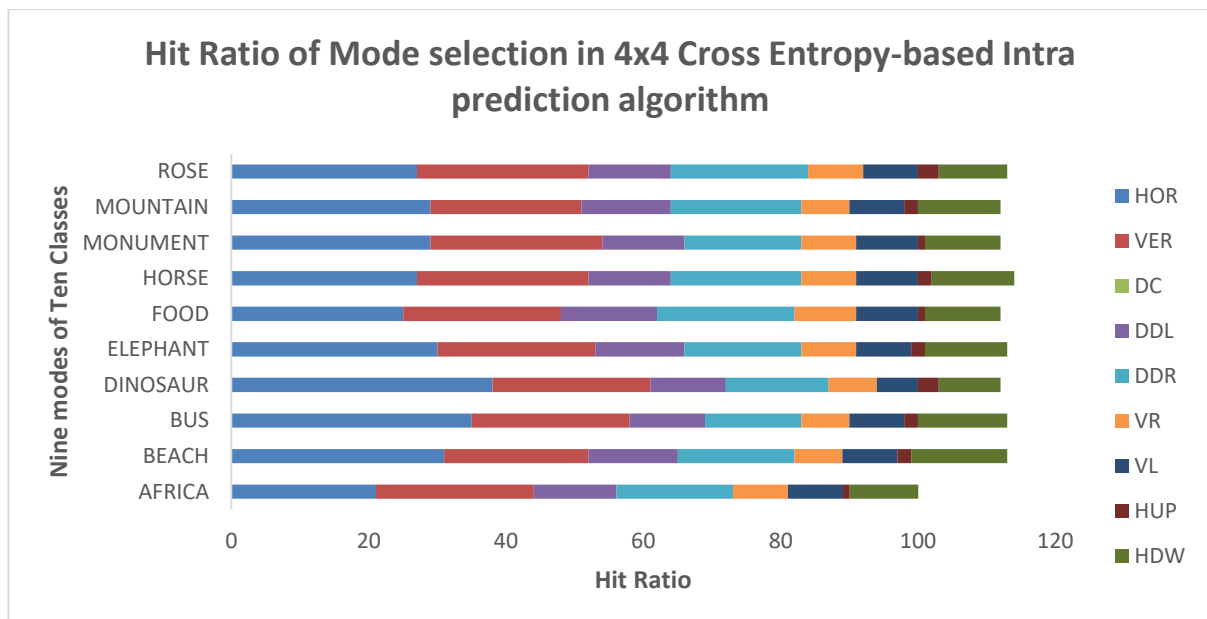


Fig 3: Hit Ratio of Mode selection in 4x4 Cross Entropy-based Intra prediction algorithm

The mode selection analysis in the Cross Entropy-based Intra Prediction Algorithm reveals a significant pattern of mode usage. The algorithm tends to avoid or skip certain modes, notably the DC and HUP modes, which are invoked less than 5% of the time. In contrast, other modes such as DDL, HOR, VER, VL, HDR, DDR, and VR are prominently used, reflecting their effectiveness in achieving compression efficiency and preserving image quality in H.264 video encoding. Figure 3 provides graphical representations of the hit ratio for mode selection in the 4x4 Cross Entropy-based Intra Prediction Algorithm.

Table 1: Optimal mode selection in 4x4 Cross Entropy-based Intra prediction

Algorithms	Skipped modes	Can be neglected	Prominent Mode
Cross Entropy-based Intra prediction algorithm	DC	HUP (Called only less than 5%)	DDL, HOR, VER, VL, HDR, DDR, VR

Table 1 presents the optimal mode selection for the 4x4 Cross Entropy-based Intra Prediction Algorithm. The table shows that the DC mode is consistently skipped, while the HUP mode is rarely utilized, being called less than 5% of the time. In contrast, the DDL, HOR, VER, VL, HDR, DDR, and VR modes are prominently featured, indicating their frequent selection during the intra prediction process. Upon evaluation, the Error Entropy-based RDO algorithm demonstrated promising results. It facilitated balanced mode utilization, ensuring that all modes were equally leveraged with none being neglected, evidenced by no mode being utilized less than 5% of the time.

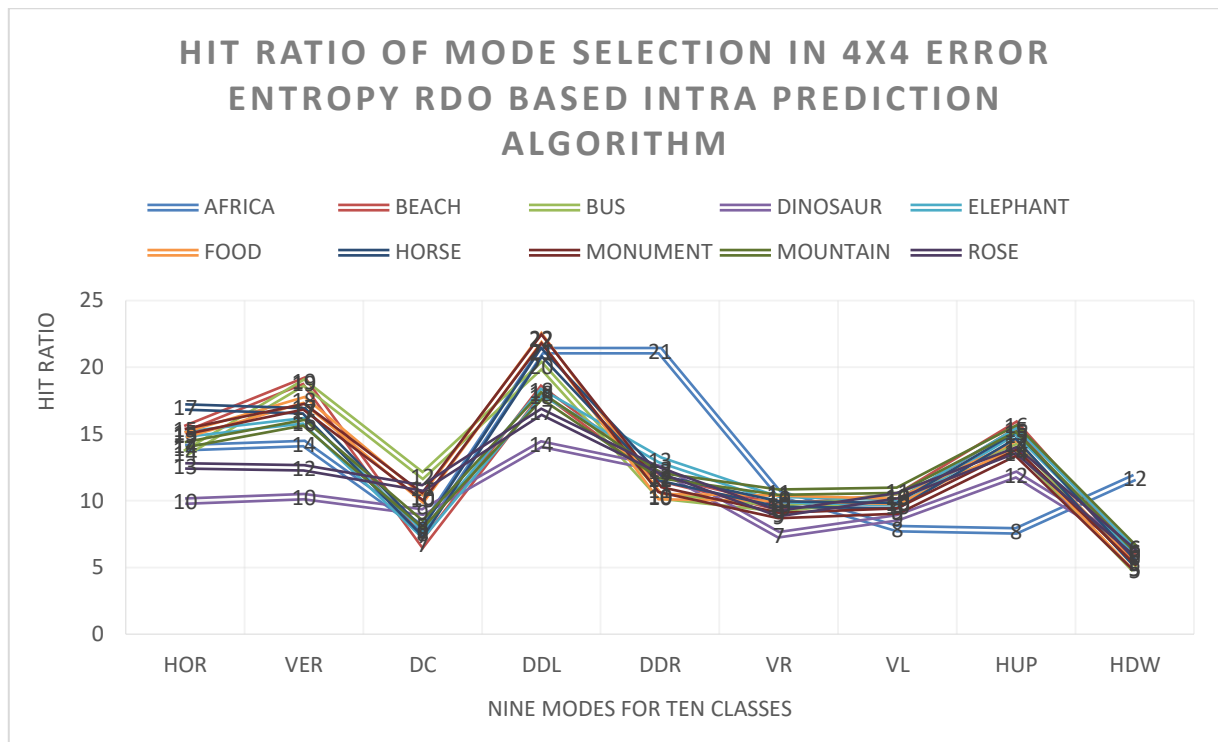


Fig 4: Hit Ratio of Mode selection in 4x4 error Entropy RDO based Intra prediction algorithm

In the Error Entropy-based RDO (Rate-Distortion Optimization) algorithm, a comprehensive analysis of mode selection reveals a striking pattern: all modes are equally utilized. This signifies a balanced distribution of mode selection, where no modes are neglected or skipped. Unlike other methods where certain modes may be favoured over others, the Error Entropy approach ensures that each prediction mode plays a significant role in optimizing the intra prediction process. Figure 3 illustrates the graphs for the Hit Ratio of Mode selection in the 4x4 error Entropy-based Intra prediction

algorithm This balanced utilization underscores the effectiveness of Error Entropy in enhancing mode selection, leading to improved compression efficiency and maintained image quality in H.264 video encoding.

Table 2 :Optimal mode selection in 4x4 Cross Entropy-based Intra prediction

Algorithms	modes	Hit Ratio	Prominent Mode
Error Entropy RDO based Intra prediction algorithm	HOR	10 -17 %	No modes called for less than 5% Hit ratio
	VER	10 -19 %	
	DC	7 -12 %	
	DDR	10 -21 %	
	DDL	14 -22 %	
	HUP	8 -16 %	
	HDW	5 -12 %	
	VR	7 -11 %	
	VL	8 -11 %	

In Table 2, the optimal mode selection in the 4x4 Cross Entropy-based Intra prediction algorithm is detailed. The Error Entropy RDO based Intra prediction algorithm showcases varying hit ratios for different modes. The Horizontal (HOR) mode exhibits a hit ratio ranging from 10% to 17%, while the Vertical (VER) mode ranges from 10% to 19%. Additionally, the DC mode maintains a hit ratio between 7% and 12%. Modes such as Double Down Left (DDL) and Double Down Right (DDR) show hit ratios ranging from 14% to 22% and 10% to 21%, respectively. Other modes like Horizontal Up (HUP), Horizontal Down (HDW), Vertical Right (VR), and Vertical Left (VL) exhibit hit ratios between 5% and 16%.

In comparing the two algorithms, it becomes evident that they each possess distinct strengths and trade-offs. While the Cross Entropy-based algorithm prioritizes compression efficiency, achieving higher compression ratios, it may inadvertently result in higher MSE. On the contrary, the Error Entropy-based RDO algorithm excels in maintaining balanced mode utilization and lower RD cost, ultimately preserving image quality through optimized rate-distortion performance. Overall, both algorithms present viable solutions for enhancing H.264 intra prediction, offering avenues for further refinement and application in real-world video encoding scenarios.

V. CONCLUSION

Both the Error Entropy-based and Cross Entropy-based algorithms offer valuable contributions to the realm of intra prediction in H.264 video encoding. The Error Entropy-based RDO algorithm demonstrates a balanced utilization of prediction modes, ensuring that no mode is neglected, and all contribute significantly to the compression process. By considering error entropy and distortion calculations, this method optimizes mode selection, resulting in improved compression efficiency and maintained image quality. On the other hand, the Cross Entropy-based algorithm prioritizes accuracy in pixel prediction by minimizing cross-entropy loss between original and predicted macroblocks. While certain modes may be skipped or neglected, the algorithm identifies prominent modes that closely resemble the original data, leading to enhanced compression ratios and preserved image fidelity. In essence, both algorithms offer unique advantages: the Error Entropy-based RDO method ensures comprehensive mode utilization, while the Cross Entropy-based approach prioritizes accuracy in prediction. By leveraging the strengths of these innovative techniques, H.264 intra prediction stands to achieve higher efficiency and quality in video encoding applications.

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