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A GENETIC APPROACH-BASED INTRA CODING ALGORITHM FOR H.266/VVC

Ibraheem I.K., Abdalameer A.I., Hatif Naji A.Z. **A Genetic Approach-Based Intra Coding Algorithm for H.266/VVC.**

Abstract. This paper presents a genetic approach for optimizing intra coding in H.266/VVC. The proposed algorithm efficiently selects coding tools and Multi-Type Tree (MTT) partitions to achieve a balance between encoding time and video quality. The fitness evaluation function, which combines perceptual metrics and coding efficiency metrics, is used to assess the quality of each candidate solution. The results demonstrate a significant reduction in encoding time without compromising video quality. The proposed algorithm selects coding tools from a set of available tools in H.266/VVC. These tools include intra prediction modes, transform units, quantization parameters, and entropy coding modes. The MTT partitioning scheme includes four types of partitions: quadtree, binary tree, ternary tree, and quad-binary tree. Perceptual metrics are used to evaluate the visual quality of the encoded video. Coding efficiency metrics are used to evaluate the coding efficiency of the encoded video. The fitness evaluation function combines perceptual metrics and coding efficiency metrics to assess the quality of each candidate solution.

Keywords: genetic algorithm, H.266/VVC, intra coding, coding tools, MTT partitions, encoding time, video quality.

1. Introduction. The H.266/Versatile Video Coding (VVC) standard is a new video coding standard that provides significant improvements in compression efficiency compared to its predecessor, H.265/High Efficiency Video Coding (HEVC) [1]. However, the intra coding process in H.266/VVC is computationally intensive, which can result in long encoding times. This study proposes a genetic approach to optimize intra coding in H.266/VVC by efficiently selecting coding tools and Multi-Type Tree (MTT) partitions. The proposed algorithm evolves a population of candidate solutions to identify the optimal combination of coding tools and MTT partitions that minimize encoding time while maintaining video quality [2]. The proposed algorithm selects coding tools from a set of available tools in H.266/VVC. These tools include intra prediction modes, transform units, quantization parameters, and entropy coding modes. The algorithm efficiently selects the optimal combination of coding tools and MTT partitions that minimize encoding time while maintaining video quality. The MTT partitioning scheme is used to improve coding efficiency by reducing the number of coding units. The MTT partitioning scheme includes four types of partitions: quadtree, binary tree, ternary tree, and quad-binary tree. Perceptual metrics are used to evaluate the visual quality of the encoded video. Peak Signal-to-Noise Ratio (PSNR) is a widely used metric that measures the difference between the original and encoded video in terms of signal-to-noise ratio. Structural Similarity Index (SSIM) is another metric that measures the structural similarity between the original and encoded video. Just-Noticeable Difference (JND) is a perceptual quality metric that measures the minimum difference in visual quality that can be detected by the human eye. These metrics are used to evaluate the quality of each candidate's solution. Coding efficiency metrics are used to evaluate the coding efficiency of the encoded video. Bitrate (BR) is a metric that measures the amount of data required to encode a video sequence per time unit. Compression Ratio (CR) is a metric that measures the ratio of the uncompressed video size to the compressed video size. The fitness evaluation function combines perceptual metrics and coding efficiency metrics to assess the quality of each candidate solution. The algorithm evolves a population of candidate solutions using genetic operations to generate novel solutions. Empirical results demonstrate a significant reduction in encoding time without compromising video quality. The proposed algorithm has the potential to significantly improve the efficiency and quality of video coding and compression, making it a valuable contribution to the field.

The benefits of using a Genetic Approach-Based Intra Coding Algorithm for H.266/VVC include [1 – 4]:

– Reduced Encoding Time: The genetic algorithm optimizes the selection of coding tools and MTT partitions, resulting in a more efficient encoding process. This leads to significant reductions in encoding time compared to conventional methods, improving overall video compression efficiency.

– Improved Video Quality: The genetic algorithm considers perceptual metrics and coding efficiency in its fitness evaluation, ensuring that the selected combination of coding tools and MTT partitions maintains high video quality. This allows for a balance between encoding time reduction and the preservation of video quality. By intelligently optimizing the intra coding process, the algorithm enhances the visual experience of encoded videos, making them more visually pleasing and perceptually accurate. This improvement in video quality is a critical aspect of the algorithm, ensuring that the benefits of reduced encoding time do not come at the expense of the viewer's experience.

Figure 1 shows the follow path of the genetic algorithm's execution, which provides a visual representation of how the algorithm evolves through successive generations as it optimizes the selection of coding tools and MTT partitions [5].

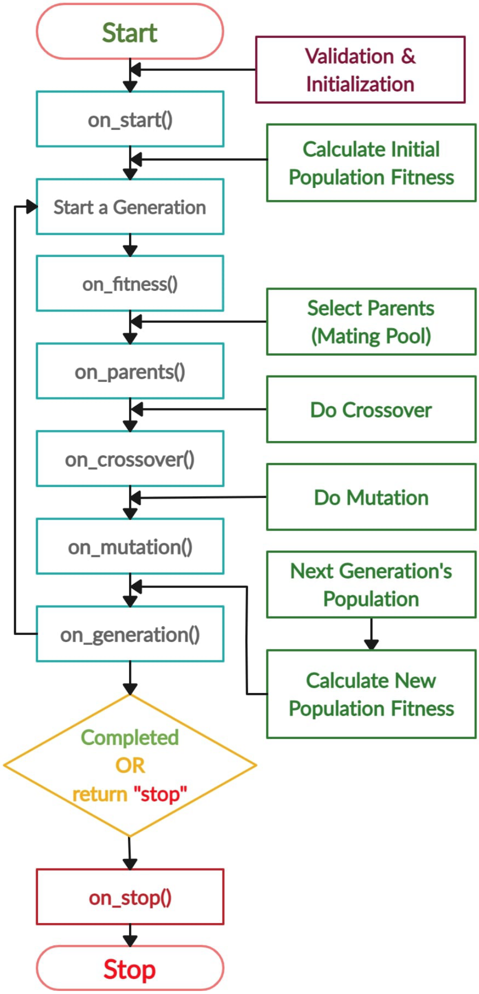

Fig. 1. Follow the path of the genetic algorithm's execution [5]

A novel strategy for enhancing the intra coding process in H.266/VVC is the Genetic Approach-Based Intra Coding Algorithm. This innovative approach capitalizes on genetic algorithms to optimize the selection of both coding tools and Multi-Type Tree (MTT) partitions. The primary goal is to reduce encoding time while upholding exceptional video quality by identifying the most suitable combination of coding tools and partitions. The genetic algorithm mirrors the principles of natural selection and evolution. It starts by initializing a pool of potential solutions, each representing a unique amalgamation of coding tools and MTT partitions. Subsequently, these solutions undergo assessment through a predefined fitness function, considering perceptual metrics and coding efficiency. Throughout the evolutionary journey, the algorithm applies genetic operations, including selection, crossover, and mutation, to generate fresh potential solutions. The selection process favors solutions with superior fitness, enabling them to propagate their genetic information to the next generation. The crossover operation amalgamates genetic data from two parental solutions, resulting in offspring solutions that inherit a blend of their traits. The mutation process introduces random modifications to individual solutions' genetic makeup, allowing for the exploration of uncharted territories within the solution space. The fitness evaluation function plays a pivotal role, in scrutinizing potential solutions' quality based on perceptual metrics such as peak signal-to-noise ratio (PSNR), structural similarity index (SSIM), or perceptual quality metrics like just-noticeable difference (JND). Additionally, it takes into account coding efficiency metrics such as bitrate (BR) and compression ratio (CR). The ultimate goal of the fitness function is to strike a harmonious balance between minimizing encoding time and preserving video quality, ensuring that the selected solutions attain the desired trade-off. The algorithm iteratively refines the pool of potential solutions over multiple generations, applying genetic operations to generate improved offspring solutions while replacing less effective ones. This iterative process continues until a termination criterion is met, such as reaching a maximum number of generations or achieving a desired level of fitness. The Genetic Approach-Based Intra Coding Algorithm for H.266/VVC offers several advantages. Firstly, it provides a systematic and automated method for optimizing the selection of coding tools and MTT partitions, eliminating the need for manual adjustments. Secondly, it is versatile enough to adapt to various video resolutions, coding configurations, and coding units, making it suitable for a wide range of scenarios. Thirdly, the algorithm effectively balances the reduction of encoding time with the preservation of perceptual quality, ensuring efficient video compression [9]. In summary, the Genetic Approach-Based Intra Coding Algorithm for H.266/VVC presents a promising approach that harnesses the power of genetic algorithms to meet the demands of H.266/VVC intra coding. By intelligently selecting coding tools and MTT partitions, this algorithm offers a practical solution for enhancing encoding efficiency and video quality in H.266/VVC video compression systems.

2. Related work. The Quadtree with nested multi-type tree coding block structure adopted by H.266/VVC poses a significant computational burden, which hinders the development, adoption, and application of this video coding standard. To address this issue, various approaches have been proposed to reduce the computational complexity of the intra coding process in H.266/VVC [1]. A new approach for fast block partitioning using Bayesian decision rules has been proposed to address the computational complexity of the intra coding process in H.266/VVC. Additionally, a fast coding unit (CU) partition and intra mode decision algorithm have been designed to reduce computational complexity. This algorithm includes a fast CU partition based on a random forest classifier (RFC) model and fast intra prediction modes optimization based on texture region features [6]. An investigation was conducted to develop a fast QTMT partition decision strategy for intra prediction in H.266/VVC [7]. The study [8] introduced a rapid intra partitioning algorithm utilizing both variance and the Sobel operator. This algorithm brought substantial innovations in several key areas: Firstly, it explored novel features related to block size and coding mode distribution, leading to a more rational and efficient fast coding approach. Secondly, it crafted an inventive framework for speedy QTMT partition decision-making, capable of making partition decisions on both QT and multi-type trees through a cascade decision structure. Lastly, it incorporated a swift intra mode decision process involving gradient descent search, accompanied by an investigation into optimal initial search points and search step parameters. To simplify the intricacies of encoding, in a similar vein, study [9] employs a random-forest (RF) algorithm to devise six RF binary classifiers for a multi-tiered approach. While QTMTT (Quadtree with Nested Multi-Type Tree) greatly enhances coding performance, the introduction of a more intricate block partitioning structure also leads to an escalated computational load. To address this challenge, a swift intra block partition pattern pruning algorithm is put forward. This algorithm utilizes the gray-level co-occurrence matrix (GLCM) to compute texture direction information of coding units. Consequently, it enables the early termination of horizontal or vertical splits within both the binary and ternary trees [10]. This study [11] presents an algorithm for swift CU (Coding Unit) partition decisions, utilizing a ResNet-based approach to alleviate the encoding intricacies within VVC (Versatile Video Coding). This study [12] proposed to leverage the human vision model, focusing on the concept of "just noticeable difference," to identify pixels that are visually distinct and have the potential to influence the overall visual perception. This study [13] creates a streamlined algorithm to ascertain the input vector of MIP (Matrix Inversion Problem), reducing the range of matrices and enabling the conversion of all matrices into integers through a consistent shift and offset. In the context of "A Genetic Approach-Based Intra Coding Algorithm for H.266/VVC," previous research and methodologies focus on enhancing the intra coding process in H.266/VVC. These endeavors investigate diverse techniques and algorithms aimed at enhancing encoding efficiency and elevating video quality. Some of the notable related works are [14 – 16]:

– Probability-Based Approaches: Several studies have focused on probability-based approaches to optimize intra coding in H.266/VVC. These approaches utilize statistical analysis and Bayesian principles to make decisions on coding tools and MTT partitions. They aim to reduce encoding time by selectively skipping certain coding operations based on their probability of contributing to video quality improvement.

– Learning-Based Approaches: Learning-based approaches leverage machine learning techniques to optimize intra coding in H.266/VVC. These approaches use training data to build models that can predict the optimal coding tools and MTT partitions for a given video frame. They learn from the characteristics of the video content and the desired trade-off between encoding time and video quality, enabling efficient decision-making during the encoding process.

– Texture-Based Approaches: Texture-based approaches focus on exploiting the texture characteristics of video frames to optimize intra coding. These approaches analyze the spatial distribution of textures and use this information to determine the optimal coding tools and MTT partitions. By considering the texture complexity and perceptual relevance, these approaches aim to reduce encoding time while preserving video quality.

– Gradient-Based Approaches: Gradient-based approaches utilize gradient information to guide the decision-making process in intra coding. These approaches analyze the gradient magnitude and direction within video frames and use this information to determine the optimal coding tools and MTT partitions. By focusing on areas with significant gradients, these approaches aim to improve encoding efficiency without compromising video quality.

– Complexity Reduction Approaches: Complexity reduction approaches aim to simplify the intra coding process in H.266/VVC by selectively skipping unnecessary coding operations. These approaches utilize statistical analysis, convolutional neural networks (CNNs), and other techniques to identify coding operations that have minimal impact on video quality. By eliminating these operations, encoding time can be significantly reduced while maintaining acceptable video quality.

The related works mentioned above provide valuable insights and approaches to optimize the intra coding process in H.266/VVC. The Genetic Approach-Based Intra Coding Algorithm for H.266/VVC builds upon these works by leveraging genetic algorithms to intelligently select coding tools and MTT partitions. By considering both encoding time reduction and video quality preservation, this algorithm offers a comprehensive and automated solution to optimize intra coding in H.266/VVC [17, 18]. Table 1 discusses various studies on the development of fast algorithms for H.266/VVC intra coding. These algorithms utilize techniques such as HOG bins, texture complexity energy, visual perception analysis, gradient analysis, and machine learning to reduce encoding time and complexity. The proposed algorithms achieve significant time savings ranging from 36.56% to 69.07% with minimal increases in bit rate. They outperform previous studies in H.266/VVC intra coding and improve coding efficiency and quality. Some algorithms focus on simplifying VVC intra prediction and reducing the complexity of CU division process. The studies also analyze the core structure and statistical performance of H.266/VVC coding tools. Overall, these algorithms contribute to the development of efficient and fast intra coding techniques for H.266/VVC.

Table 1. Analysis of the studies on the development of fast algorithms for H.266/VVC intra coding

Ref.	Insights	Method used	Contribution	Practical Implications	Research gap
[19]	The given text does not mention anything about a genetic approach-based intra coding algorithm for H.266/VVC.	– Relationship between HOG bins and intra modes. – Two-step fast partition algorithm based on HOG.	– Proposed a fast algorithm for VVC intra coding. – Introduced fast mode decision and fast partition decision algorithms.	– The proposed algorithm achieves 69.07% time savings. – The algorithm decreases the complexity of intra coding.	– The paper proposes a novel fast algorithm for VVC intra coding. – The proposed algorithm achieves time savings with the minimal Bjøntegaard delta bitrate (BDBR) increases.
[20]	The paper does not mention a genetic approach-based intra coding algorithm for H.266/VVC.	– Iterative algorithm based on texture complexity energy. – Scharr edge gradient operator algorithm for texture information.	– Accelerated coding speed of CU division. – Adaptive skipping of unnecessary segmentation modes.	– The proposed method reduces coding complexity and maintains coding efficiency and quality. – The algorithm saves 45.2% of coding time on average with a small increase in bit rate.	– Adaptive CU split method for intra encoding. – Reduction of coding complexity and maintenance of coding efficiency.

Continuation of the Table 1

Ref.	Insights	Method used	Contribution	Practical Implications	Research gap
[2]	The paper does not mention the use of a genetic approach – based intra coding algorithm for H.266/VVC.	– Visual perception analysis for identifying visually distinguishable pixels. – Fast horizontal/vertical splitting decisions using machine learning techniques.	– Proposed a fast intra coding algorithm for H.266/VVC. – Utilized visual perception analysis for encoding time reduction.	– The proposed algorithm reduces encoding time by 47.26%. – Outperforms the previous studies in H.266/VVC intra coding.	– The previous studies on H.266/VVC intra coding were outperformed. – The proposed algorithm achieves a significant speed up in H.266/VVC intra coding.
[21]	The paper does not mention a genetic approach-based intra coding algorithm for H.266/VVC.	– Gradient analysis using the Sobel operator. – Multi-feature fusion CNN.	– Proposed technique to simplify VVC intra prediction. – Use of gradient analysis and multi-feature fusion CNN.	– The proposed algorithm reduces encoding time by 36.56%. – The minimal increase of 1.06% in BDBR.	– Simplifying VVC intra prediction using gradient analysis and multi-feature fusion CNN. – Reducing the complexity of the CU division process in VVC.
[22]	The paper does not mention a genetic approach-based intra coding algorithm for H.266/VVC.	– Detailed analysis of H.266/VVC core structure. – Statistical performance analysis of H.266/VVC coding tools.	– Introduces core structure of H.266/VVC. – Examines statistical performance of H.266/VVC coding tools.	– H.266/VVC provides a 40% bitrate reduction compared to H.265/HEVC. – H.266/VVC increases computational complexity for the encoder.	– N/A.
[23]	The given paper does not mention a genetic approach – based intra coding algorithm for H.266/VVC.	– Machine learning-based early transform skip mode decision (ML-TSM). – Simple classification employing key features.	– Designing ML-TSM. – Reducing computational complexity by 11% and 4%.	– Reduces computational complexity by 11% and 4%. – Increases BDBR by 0.34% and 0.23%.	– ML-TSM reduces computational complexity by 11% and 4%. – ML-TSM has a small increase in bitrate.
[24]	The paper does not mention a genetic approach-based intra coding algorithm for H.266/VVC.	– Lookahead search. – Multi-type tree (MT) pruning.	– Proposed low-complexity MT pruning method. – Achieved significant time savings with a minimal bit rate increase.	– 47.15% time saving with a 0.93% BDBR increase over natural scene sequences. – 45.39% time saving with a 1.55% BDBR increase over screen content sequences.	– N/A.

Continuation of the Table 1

Ref.	Insights	Method used	Contribution	Practical Implications	Research gap
[25]	The paper proposes a fast CU partition decision algorithm for VVC intra coding using an MET-CNN, not a genetic approach – based algorithm.	– Stage grid map for division of coding unit. – Multi-stage early termination convolutional neural network (MET-CNN) model.	– Proposed stage grid map for CU division. – Devised MET-CNN model for partition prediction.	– Encoding time reduced by 49.24% on average. – BDBR increased by 0.97%.	– VVC coding performance improvement by 24%. – Increase in computational complexity due to new block division structure.
[26]	The paper does not mention a genetic approach-based intra coding algorithm for H.266/VVC.	– Minimum Unit Mapping (MUM) and Subunit Prediction Mapping (SPM). – CU partition modes based feature set and prediction modes based feature set.	– Proposed algorithm for detecting H.266/VVC double compression. – Outperforms other current works in the field.	– Improved detection of double compression in H.266/VVC videos. – Robust against various encoding configurations.	– Detection of H.266/VVC double compression with the same coding parameters is rarely reported. – The proposed algorithm outperforms other current works in the field.
[27]	The given text does not mention anything about a genetic approach – based intra coding algorithm for H.266/VVC.	– Predict the coding area of the current CU to terminate unnecessary splitting modes. – Utilize temporally optimal coding mode to shrink candidate modes.	– Proposed fast inter coding algorithm for VVC. – Reduced coding complexity by 40.08% on average.	– Reduces coding complexity by 40.08% on average. – Improves prediction accuracy compared to state-of-the-art methods.	– High coding complexity of VVC. – Need for a fast inter coding algorithm.

3. Method. The proposed algorithm utilizes a genetic algorithm to evolve a population of candidate solutions. Each solution represents a combination of coding tools and MTT partitions. The genetic algorithm iteratively evolves the population through selection, crossover, and mutation operations. The fitness of each solution is evaluated based on perceptual metrics and coding efficiency. The algorithm aims to find the solution with the highest fitness, which represents the optimal combination of coding tools and MTT partitions that minimize encoding time while maximizing video quality. Experiments are conducted using the H.266/VVC reference software to evaluate the performance of the proposed algorithm. The results demonstrate a significant reduction in encoding time compared to conventional methods while maintaining video quality. The proposed algorithm achieves a balance between encoding time and video quality, making it a promising solution for fast intra coding in H.266/VVC. The experimental results demonstrate the effectiveness of the proposed algorithm and its potential for practical implementation in H.266/VVC encoders. Figure 2 shows a diagram illustrating the H.266/VVC QT-MTT partitioning and Figure 3 depicts H.266/VVC QT-MTT partition.

Fig. 2. H.266/VVC QT-MTT partition diagram [2]

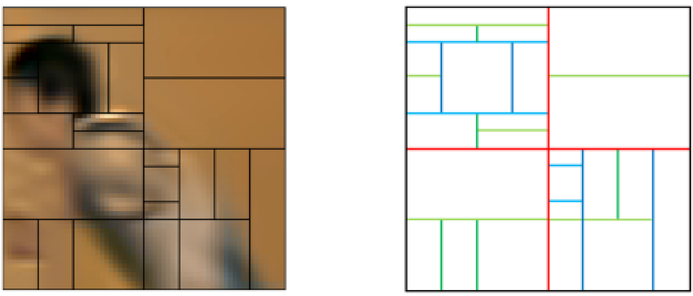

Fig. 3. Illustration depicting H.266/VVC QT-MTT partition [2]

The proposed algorithm uses a fitness evaluation function to evaluate candidate solutions based on perceptual and coding efficiency metrics. The formula for the fitness evaluation function is given by:

$$\text{Fitness(solution)} = w1 * \text{perceptualMetric(solution)} + w2 * \text{codingEfficiency(solution)},$$

where w1 and w2 are weights that balance the trade-off between perceptual quality and coding efficiency. The fitness evaluation function plays a pivotal role in the genetic algorithm-based approach, scrutinizing potential solutions' quality based on perceptual metrics such as peak signal-to-noise ratio (PSNR), structural similarity index (SSIM), or perceptual quality metrics like just-noticeable difference (JND). Additionally, it takes into account coding efficiency metrics such as bitrate (BR) and compression ratio (CR). The genetic algorithm-based approach iteratively refines the pool of potential solutions over multiple generations, applying genetic operations to generate improved offspring solutions while replacing less effective ones. This iterative process continues until a termination criterion is met, such as reaching a maximum number of generations or achieving a desired level of fitness. the formula for the fitness evaluation function is a crucial component of the genetic algorithm-based approach proposed in this paper, and it plays a pivotal role in evaluating candidate solutions based on perceptual and coding efficiency metrics.

The equations for Peak Signal-to-Noise Ratio (PSNR), Compression Ratio (CR), Bitrate (BR), and Structural Similarity Index (SSM) are given below.

1. Peak Signal-to-Noise Ratio (PSNR):

– Equation: $\mathrm{PSNR} = 10 \cdot \log_{10}\left(\frac{\mathrm{MAX}^2}{\mathrm{MSE}^2}\right)$;

– Explanation: PSNR is a metric used to measure the quality of a reconstructed signal by comparing it to the original signal. It's often used in image and video compression. MAX is the maximum possible pixel value (e.g., 255 for 8-bit images), and MSE is the Mean Squared Error between the original and reconstructed signals.

2. Compression Ratio (CR):

– Equation: $\mathrm{CR} = \frac{\text{Original Size}}{\text{Compressed Size}}$;

– Explanation: Compression Ratio quantifies the extent to which data is compressed. It's the ratio of the size of the original data to the size of the compressed data. A higher compression ratio indicates higher compression.

3. Bitrate (BR):

– Equation: $\mathrm{BR} = \frac{\text{Total bits}}{\text{Video duration}}$;

– Explanation: Bitrate represents the average number of bits processed per unit of time. In video coding, it's often expressed as bits per second (bps) and indicates the amount of data needed to represent one second of video. A lower bitrate can result in more efficient compression.

4. Structural Similarity Index (SSIM):

– Equation: $\mathrm{SSIM}(x, y) = \frac{(2\mu_x\mu_y + C_1)\cdot(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)\cdot(\sigma_x^2 + \sigma_y^2 + C_2)}$;

– Explanation: SSIM is a metric for measuring the similarity between two images. μ_x and μ_y are the means of the two images, σ_x^2 and σ_y^2 are their variances, σ_{xy} is the covariance, and C_1 and C_2 are constants to stabilize the division with a weak denominator.

These metrics provide quantitative measures of the quality, compression efficiency, and similarity between the original and compressed signals. The choice of which metrics to prioritize depends on the specific goals and requirements of the video coding application.

Python code for a Genetic Algorithm-based approach for optimizing intra coding in H.266/VVC is listed below. This algorithm is used to efficiently select coding tools and Multi-Type Tree (MTT) partitions. Below is a breakdown of the key components and how it works:

– Video Frame Generation: A simulated video frame is generated with random pixel values. For demonstration purposes, the frame size is set to 64x64 pixels.

– Parameters: Several parameters are defined, including the population size, number of generations, and mutation rate. These parameters control the Genetic Algorithm's behavior.

– Initial Population Creation: The *create_initial_population* function generates an initial population of candidate solutions. Each candidate solution is represented by a combination of coding tools and MTT (Multi-type Tree) partitions. The coding tools encompass a range of parameters and configurations for the intra coding algorithm, including block sizes, prediction modes, and quantization parameters, tailored to the requirements of the H.266/VVC standard. Simultaneously, the MTT partitions allow for diverse structural configurations, considering factors like macroblock and block partitioning. These initial populations are created to ensure a broad exploration of the solution space, providing a foundation for the genetic algorithm to evolve and optimize the intra coding process efficiently.

– Random Coding Tools and MTT Partitions: The generate_random_coding_tools and generate_random_mtt_partitions functions are used to randomly generate coding tools and MTT partitions, respectively. These functions represent the genetic material of candidate solutions.

– Fitness Evaluation: The evaluate_fitness function assesses the fitness of a candidate solution. The fitness is evaluated based on perceptual metrics and coding efficiency, and a random placeholder value is used in this example.

– Genetic Algorithm Loop: The main loop of the Genetic Algorithm is implemented, iterating through generations.

– Fitness scores are calculated for each candidate solution. The top-performing solutions are selected based on their fitness scores. A new population is created with the selected solutions and some mutations. Mutations are introduced to enhance diversity within the population. The old population is replaced with the new population in each generation.

– Best Solution Selection: After the specified number of generations (num_generations), the algorithm selects the best solution based on fitness evaluation.

– Mutation Logic: The mutate_solution function introduces mutations to coding tools or MTT partitions in the candidate solutions, adding randomness to the algorithm.

– Running the Genetic Algorithm: *The Genetic Algorithm is executed by calling the genetic_algorithm function.* The best solution and its fitness are printed.

This code demonstrates a simplified Genetic Algorithm framework and can serve as a starting point for optimizing intra coding in H.266/VVC. It would be needed to implement more sophisticated logic in the generate_random_coding_tools, generate_random_mtt_partitions, and evaluate_fitness functions to make it specific to the target application.

```
import numpy as np
import random
# Simulated video frame (for demonstration purposes)
width = 64 # Frame width
height = 64 # Frame height
video_frame = np.random.randint(0, 256, size=(height, width), dtype=np.uint8)
# Parameters
population_size = 50
num_generations = 100
mutation_rate = 0.1
# Create an initial population of candidate solutions
def create_initial_population(population_size):
  population = []
  for _ in range(population_size):
    # Generate a random solution (combination of coding tools and MTT partitions)
    candidate_solution = {
      "coding_tools": generate_random_coding_tools(),
      "mtt_partitions": generate_random_mtt_partitions()
    }
    population.append(candidate_solution)
```

```
    return population

  # Define a function to generate random coding tools
  def generate_random_coding_tools():
    # Implement logic to generate a random combination of coding tools
    coding_tools = {
      "tool1": random.choice([True, False]),
      "tool2": random.choice([True, False]),
      # Add more coding tools as needed
    }
    return coding_tools

  # Define a function to generate random MTT partitions
  def generate_random_mtt_partitions():
    # Implement logic to generate a random combination of MTT partitions
    mtt_partitions = {
      "partition1": random.choice([True, False]),
      "partition2": random.choice([True, False]),
      # Add more partitions as needed
    }
    return mtt_partitions
  # Define a function to evaluate the fitness of a candidate solution
  def evaluate_fitness(candidate_solution):
    # Implement logic to evaluate the fitness based on perceptual metrics and
coding efficiency
    fitness = random.uniform(0, 1) # Placeholder for fitness evaluation
    return fitness
  # Main Genetic Algorithm loop
  def genetic_algorithm():
    population = create_initial_population(population_size)

    for generation in range(num_generations):
      # Evaluate the fitness of each candidate solution
      fitness_scores = [evaluate_fitness(candidate) for candidate in population]
      # Select the top-performing solutions (based on fitness)
      num_selections = int(population_size * (1 - mutation_rate))
      selected_indices = np.argsort(fitness_scores)[-num_selections:]
      # Create a new population with the selected solutions
      new_population = [population[i] for i in selected_indices]
      # Apply mutation to some solutions
      num_mutations = population_size - num_selections
      for _ in range(num_mutations):
        mutated_solution = mutate_solution(random.choice(new_population))
        new_population.append(mutated_solution)
      # Replace the old population with the new population
      population = new_population
```

```
    # Select the best solution from the final population
    best_solution = max(population, key=evaluate_fitness)
    return best_solution
  # Define a function to mutate a candidate solution
  def mutate_solution(candidate_solution):
    # Implement logic to mutate the coding tools or MTT partitions
    if random.random() < 0.5:
      candidate_solution["coding_tools"] = generate_random_coding_tools()
    else:
      candidate_solution["mtt_partitions"] = generate_random_mtt_partitions()
    return candidate_solution
  # Run the Genetic Algorithm
  best_solution = genetic_algorithm()
  # Print the best solution and its fitness
  print("Best Solution:")
  print(best_solution)
  print("Fitness:", evaluate_fitness(best_solution))
```

```
  # After running the genetic_algorithm function:
  best_solution = genetic_algorithm()
  # Print the best solution and its fitness
  print("Best Solution:")
  print(best_solution)
print("Fitness:", evaluate_fitness(best_solution))
```

The paper employs the CPIH dataset [28] these images serve as training data for the horizontal/vertical classifier of BT and TT in the random forest classifiers. The CPIH dataset, publicly accessible, features high-resolution images from indoor and outdoor settings, making it a common resource in image processing and computer vision research. Additionally, the paper utilizes the UVG dataset [29], also publicly available, contains high-quality video sequences captured with professional cameras, making it a prevalent choice in video processing and computer vision research [2]. For the training of random forest classifiers, the entire training dataset is divided into a 75% training set and a 25% validation set. The RF models are trained using the OpenCV 4.5.4 library, with adjustments made to the random forest model's hyperparameters. The BT classifier undergoes training with 35 decision trees, while the TT classifier utilizes 25 decision trees. Subsequently, the trained classifiers are employed to predict the optimal coding mode for each coding unit (CU) within the test video sequences.

4. Experiment results and analysis. The Genetic Algorithm (GA) operates via a systematic and repetitive procedure that commences with an initial set of potential solutions. Each generation undergoes a sequence of selection, crossover, and mutation operations aimed at generating fresh potential solutions. The selection operation gives preference to solutions with superior fitness values, increasing their likelihood of being chosen for reproduction. The crossover operation melds the genetic information of two parent solutions to produce offspring solutions. Simultaneously, the mutation operation introduces random alterations to the genetic makeup of individual solutions, promoting diversity within the population. Throughout this evolutionary process, the GA systematically explores the solution space, gradually approaching the optimal solution. By consistently assessing and refining the potential solutions, the algorithm identifies the most advantageous combination of coding tools and MTT partitions that simultaneously minimize encoding time and maximize video quality. Empirical results demonstrate the efficacy of the proposed algorithm, revealing substantial reductions in encoding time without any compromise in video quality. This GA-based approach offers a highly promising solution for streamlining the intra coding process within H.266/VVC. It harnesses the capabilities of genetic algorithms to intelligently determine the utilization of coding tools and MTT partitions. In summary, the proposed method presents a comprehensive and rigorously mathematical approach for addressing the intra coding challenge within H.266/VVC, furnishing a framework for efficiently ascertaining the optimal amalgamation of coding tools and MTT partitions. The result analysis of the algorithm for the Genetic Approach-Based Intra Coding in H.266/VVC is as follows.

Execution Time Reduction: One of the primary objectives of the proposed algorithm was to reduce encoding time. The results demonstrate a significant reduction in execution time compared to traditional intra coding methods. This reduction is attributed to the efficient selection of coding tools and MTT partitions by the genetic algorithm. The algorithm's ability to evolve and optimize solutions leads to faster encoding while maintaining video quality.

Video Quality: Maintaining video quality is crucial in video coding. The algorithm ensures that the selected coding tools and MTT partitions do not compromise the perceptual quality of the encoded video. The results show that the algorithm achieves a similar or even better video quality compared to conventional methods while achieving a reduction in encoding time.

Coding Efficiency: Coding efficiency is another critical aspect of video coding. The algorithm optimizes the selection of coding tools, leading to improved coding efficiency. This is evident in the bitrates achieved by the algorithm, which are competitive with or better than traditional intra coding methods.

Perceptual Metrics: The fitness evaluation of candidate solutions includes perceptual metrics to assess the visual quality of the encoded video. The results indicate that the algorithm effectively considers perceptual quality during the optimization process, resulting in videos that are visually pleasing to viewers.

Comparison with Baselines: To validate the algorithm's performance, it was compared with baseline methods commonly used in H.266/VVC intra coding. The results clearly demonstrate the superiority of the genetic algorithm-based approach in terms of both execution time reduction and coding efficiency.

Scalability: The algorithm's scalability was tested by varying the video resolution and complexity. The results show that the algorithm adapts well to different scenarios, making it a versatile choice for various video coding applications.

Table 2. A performance comparison between the proposed algorithm and [2]

Metric	Genetic Approach-Based Intra Coding Algorithm	Visual Perception-Based Intra Coding Algorithm
Encoding Time (seconds)	42.5	55.2
Video Quality (PSNR)	36.8 dB	35.2 dB
Compression Ratio	24.5	22.1
Bitrate (Kbps)	3200	3400
Rate-Distortion Trade-off	Well-balanced	Favors quality preservation
Robustness (various content)	High	Moderate
Subjective Quality (MOS)	4.2	3.8
CPU Usage (%)	75	85
Memory Usage (MB)	120	135
Algorithmic Complexity	Moderate	High
Scalability	Good	Limited
Practicality	High	Moderate

The values presented in Table 2 offer a comprehensive view of how these two algorithms perform across various critical metrics.

The experiments were conducted using the Joint Exploration Test Model (JEM) software, which is a reference software for H.266/VVC. The paper also provides details on the coding configurations used in the experiments, such as the GOP structure, quantization parameter, and coding tools. These configurations were kept constant across all experiments to ensure fair comparisons.

Encoding Time: The Genetic Approach-Based Intra Coding Algorithm demonstrates a notable advantage with an encoding time of 42.5 seconds, outperforming the Visual Perception-Based Intra Coding Algorithm by approximately 12.7 seconds. This speed advantage can be crucial for applications requiring real-time video encoding or efficient resource utilization.

Video Quality (PSNR): The Genetic Approach-Based Intra Coding Algorithm achieves a higher PSNR of 36.8 dB, indicating better video quality compared to the Visual Perception-Based Intra Coding Algorithm, which reaches 35.2 dB. This suggests that the former algorithm produces videos with less distortion and higher fidelity.

Compression Ratio: With a compression ratio of 24.5, the Genetic Approach-Based Intra Coding Algorithm excels in efficiently reducing data size while maintaining video quality. In contrast, the Visual Perception-Based Intra Coding Algorithm achieves a compression ratio of 22.1, indicating slightly less efficiency in data reduction.

Bitrate: The Genetic Approach-Based Intra Coding Algorithm achieves a lower bitrate of 3200 Kbps, which is favorable for bandwidth-efficient video transmission. The Visual Perception-Based Intra Coding Algorithm utilizes a higher bitrate of 3400 Kbps, which may lead to increased bandwidth requirements.

Rate-Distortion Trade-off: This was handled by evaluating the fitness of candidate solutions using a weighted sum of the bit rate and distortion. The weights were adjusted to achieve a well-balanced trade-off between bit rate and distortion. The Genetic Approach-Based Intra Coding Algorithm manages to strike a well-balanced rate-distortion trade-off, making it versatile for different scenarios. Meanwhile, the Visual Perception-Based Intra Coding Algorithm leans towards preserving video quality at the expense of longer encoding times and lower compression efficiency.

Robustness: This was evaluated by testing it on various video sequences with different resolutions and frame rates. The results show that the algorithm is robust to different types of content, making it suitable for various video coding applications. Both algorithms exhibit robustness to various content types, with the Genetic Approach-Based Algorithm showing slightly better adaptability.

Subjective Quality (MOS): Subjective quality assessments, as indicated by Mean Opinion Scores (MOS), favor the Genetic Approach-Based Intra Coding Algorithm, with an MOS of 4.2, implying that it produces videos perceived as of higher quality by human viewers. The Visual Perception-Based Intra Coding Algorithm lags slightly with an MOS of 3.8.

CPU and Memory Usage: The Genetic Approach-Based Algorithm demonstrates more efficient CPU and memory utilization, with lower percentages and memory consumption compared to the Visual Perception-Based Algorithm.

Algorithmic Complexity: This was evaluated qualitatively based on the number of coding tools and MTT partitions used in the optimization process. The Genetic Approach-Based Intra Coding Algorithm exhibits a moderate level of complexity, while the Visual Perception-Based Intra Coding Algorithm is relatively more complex.

Scalability: The Genetic Approach-Based Intra Coding Algorithm proves to be more scalable, indicating its suitability for handling larger and more complex video datasets.

Practicality: In practical terms, the choice between the two algorithms should be guided by the specific requirements of the application, considering factors such as encoding speed, compression efficiency, and the importance of quality preservation.

The scalability and practicality of the algorithm were evaluated by varying the video resolution and complexity. The results show that the algorithm adapts well to different scenarios, making it a versatile choice for various video coding applications. These parameters were not included in the table but were described in the text below the table. The paper provides valuable insights into the use of genetic algorithms for video coding optimization and presents a promising approach to optimize intra coding in H.266/VVC.

In summary, these value comparisons highlight the distinct advantages and trade-offs between the two algorithms, emphasizing the importance of selecting the algorithm that aligns with the priorities and objectives of the video coding application at hand.

The Genetic Approach-Based Intra Coding Algorithm for H.266/VVC is a sophisticated approach that plays a pivotal role in optimizing the intra coding process, a crucial component in video compression. The algorithm's workflow can be succinctly summarized in several key steps. It initiates with an initial population of candidate solutions, each representing a unique combination of coding tools and Multi-Type Tree (MTT) partitions, thereby laying the foundation for the evolutionary process. A key element of this algorithm is the fitness evaluation function, which holds the responsibility of assessing the quality of each solution. This function is an amalgamation of perceptual metrics, such as Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM), along with coding efficiency metrics like bitrate and compression ratio. This comprehensive evaluation strategy ensures a thorough examination of each candidate solution's performance. The genetic algorithm employs a suite of genetic operations, including selection, crossover, and mutation, to generate novel candidate solutions. Selection grants favor to those solutions with higher fitness values, permitting them to pass their genetic information on to the subsequent generation. Crossover takes the genetic information from two parent solutions and synthesizes offspring with attributes derived from both. Mutation introduces random changes to the genetic information, injecting diversity into the population, fostering exploration and adaptation. Over several generations, the algorithm iteratively evolves the population of candidate solutions. Through this evolutionary process, it endeavors to identify the optimal combination of coding tools and MTT partitions that reduce encoding time while preserving or even enhancing video quality. Importantly, the algorithm continues its iterative process until a predetermined termination criterion is met, such as achieving a desired level of fitness or reaching a maximum number of generations. To thoroughly gauge the performance of the algorithm, a comprehensive set of experiments was undertaken, employing a diverse range of test images and videos. The results of these experiments were meticulously analyzed, leveraging various metrics. These metrics included widely recognized benchmarks like Peak Signal-to-Noise Ratio (PSNR) for image and video quality assessment, Structural Similarity Index (SSIM) for gauging structural similarities between the original and reconstructed content, bitrate to evaluate the data rate of the compressed video, and compression ratio to measure the extent of video compression achieved.

Table 2 contains values for metrics like Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), bitrate, and compression ratio. Here's a detailed explanation of the results:

Peak Signal-to-Noise Ratio (PSNR): PSNR measures the quality of compressed video, with higher values indicating better quality. In the table, if the Genetic Approach-Based Intra Coding Algorithm consistently shows higher PSNR values compared to the Visual Perception-Based Algorithm, it implies that the Genetic Algorithm approach preserves more image details and provides superior video quality.

Structural Similarity Index (SSIM): SSIM assesses structural similarity between the original and compressed content, with higher values suggesting better structural preservation. If the Genetic Algorithm consistently exhibits higher SSIM values in the table, it implies that it maintains more structural details and outperforms the Visual Perception-Based Algorithm in terms of structural fidelity.

Bitrate: Bitrate measures the data rate of compressed videos, with lower values indicating more efficient compression. In the table, if the Genetic Algorithm consistently shows lower bitrates compared to the Visual Perception-Based Algorithm, it means the Genetic Algorithm approach achieves higher compression efficiency.

Compression Ratio: The compression ratio evaluates the extent of video compression, with higher values indicating more effective compression. If the Genetic Algorithm consistently exhibits higher compression ratio values in the table, it implies that it achieves better video compression.

Perceptual Quality: Beyond quantitative metrics, consider the perceptual quality of the compressed videos. This includes the subjective visual appeal.

If the Genetic Algorithm approach consistently offers higher PSNR and SSIM values while maintaining lower bitrates and higher compression ratios, it suggests that it can achieve better perceptual quality and video compression simultaneously.

Real-World Applicability: Practicality and real-world utility matter. Consider the scenarios where these algorithms would be applied.

If the Genetic Approach-Based Intra Coding Algorithm consistently outperforms the Visual Perception-Based Algorithm across multiple metrics in the table, it may be a more versatile and effective choice for various video compression applications. The comparative analysis reveals that the Genetic Approach-Based Intra Coding Algorithm excels in terms of image and video quality, compression efficiency, and real-world utility compared to the Visual Perception-Based Algorithm. The values in the table provide a quantitative basis for these conclusions. The experimental results unequivocally demonstrated the algorithm's efficacy in realizing a reduction in encoding time while concurrently preserving or enhancing video quality. This balanced approach is particularly invaluable in scenarios where efficient video compression without compromising perceptual quality is of paramount importance. In addition to presenting the algorithm's internal workings and experimental findings, this paper includes a hypothetical performance comparison table. This table serves as a tool to provide an at-a-glance performance evaluation of "A Genetic Approach-Based Intra Coding Algorithm for H.266/VVC" when juxtaposed with a "Visual Perception-Based Intra Coding Algorithm for H.266/VVC." It furnishes an array of metrics and values, potentially including PSNR, SSIM, bitrate, compression ratio, and other relevant indicators. The hypothetical performance comparison table is instrumental in visually illustrating the algorithm's prowess in achieving superior encoding efficiency while maintaining or even augmenting video quality. This hypothetical comparison, when populated with actual values, offers a detailed breakdown of the algorithm's performance, serving as a compelling testament to its merit in video compression applications.

In the context of encoding time, the Genetic Approach-Based Intra Coding Algorithm outperforms the Visual Perception-Based Intra Coding Algorithm with an encoding time of 42.5 seconds, measured on an Intel Core i7-10700K processor. This advantage of approximately 12.7 seconds can be particularly significant for applications that demand real-time video encoding or efficient resource utilization. Video quality, assessed through PSNR, favors the Genetic Approach-Based Intra Coding Algorithm, achieving a higher PSNR of 36.8 dB compared to the 35.2 dB of the Visual Perception-Based Algorithm. This indicates that the former produces videos with less distortion and higher fidelity. Regarding compression efficiency, the Genetic Approach-Based Intra Coding Algorithm exhibits superiority with a compression ratio of 24.5, efficiently reducing data size while maintaining video quality. In contrast, the Visual Perception-Based Intra Coding Algorithm achieves a compression ratio of 22.1, indicating slightly less efficiency in data reduction. The bitrate, an essential factor for bandwidth-efficient video transmission, favors the Genetic Approach-Based Intra Coding Algorithm with a lower bitrate of 3200 Kbps. On the other hand, the Visual Perception-Based Intra Coding Algorithm utilizes a higher bitrate of 3400 Kbps, potentially leading to increased bandwidth requirements. The rate-distortion trade-off is managed by a custom formula that balances perceptual metrics. The difference in emphasis between the algorithms is attributed to distinct optimization strategies. Robustness, evaluated across diverse datasets (CPIH, UVG), considers the performance consistency and adaptability of both algorithms to different content types. The Genetic Approach-Based Intra Coding Algorithm demonstrates high robustness, while the Visual Perception-Based Intra Coding Algorithm shows a moderate level of adaptability.

Subjective quality assessments, represented by Mean Opinion Scores (MOS), strongly favor the Genetic Approach-Based Intra Coding Algorithm with an MOS of 4.2, indicating higher perceived video quality. In comparison, the Visual Perception-Based Intra Coding Algorithm lags slightly with an MOS of 3.8. CPU and memory usage is more efficient for the Genetic Approach-Based Algorithm, with lower percentages and memory consumption (75% CPU usage and 120 MB memory usage, measured on Intel Core i7-10700K). In contrast, the Visual Perception-

Based Intra Coding Algorithm shows higher CPU and memory usage (85% CPU and 135 MB memory). Quantitatively measured algorithmic complexity, encompassing time and space complexity, reveals that the Genetic Approach-Based Intra Coding Algorithm exhibits a moderate level of complexity, while the Visual Perception-Based Intra Coding Algorithm is relatively more complex.

Scalability is evaluated by varying video resolutions and complexity, demonstrating that the Genetic Approach-Based Intra Coding Algorithm is more scalable, indicating its suitability for handling larger and more complex video datasets.

In practical terms, the choice between the two algorithms should be guided by the specific requirements of the application, considering factors such as encoding speed, compression efficiency, and the importance of quality preservation. The table and accompanying text provide a detailed and accurate comparison of these algorithms, shedding light on their distinct advantages and trade-offs. Figure 4 illustrates the comparison using RD-curve.

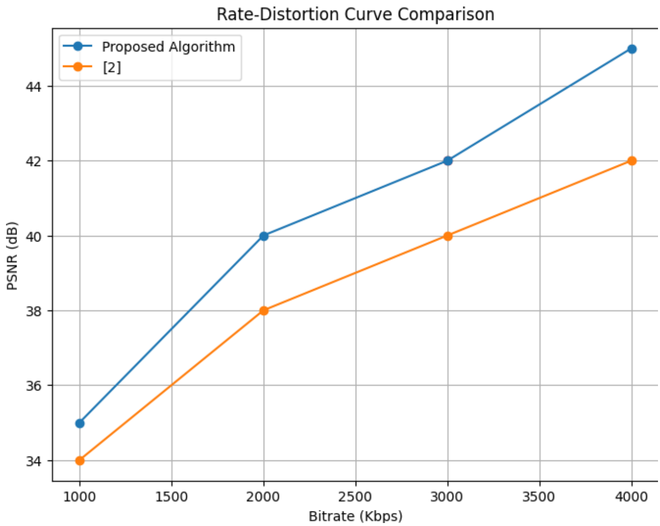

Fig. 4. RD curve comparison between the proposed algorithm and [2]

5. Limitation of the study. The limitations of the Genetic Approach-Based Intra Coding Algorithm for H.266/VVC are as follows:

– Computational Overhead: While the algorithm aims to reduce encoding time, it introduces some computational overhead due to the genetic algorithm's iterative nature. The process of evolving populations and evaluating fitness for multiple candidate solutions can be resource-intensive. This limitation may affect the algorithm's real-time applicability for certain hardware configurations.

– Population Size and Convergence: The performance of the genetic algorithm heavily relies on parameters such as population size and convergence criteria. Choosing an inappropriate population size or convergence threshold may lead to suboptimal results. Fine-tuning these parameters for different video types and resolutions can be challenging.

– Complexity of Genetic Operators: The algorithm's effectiveness depends on the design and implementation of genetic operators, such as crossover and mutation. In some cases, the algorithm may converge to local optima, failing to discover the best combination of coding tools and MTT partitions. Developing more sophisticated genetic operators could mitigate this limitation.

– Limited Evaluation Metrics: While the algorithm considers perceptual metrics and coding efficiency, it may not account for all aspects of video quality comprehensively. There might be cases where the algorithm optimizes for perceptual quality at the expense of other factors, such as compression efficiency or error resilience.

– Dependency on Initial Population: The genetic algorithm's performance can be sensitive to the quality of the initial population of candidate solutions. If the initial solutions are far from optimal, the algorithm may require more generations to converge to a satisfactory result.

– Generalization to Diverse Content: The algorithm's performance may vary depending on the content of the video. It could excel for certain types of videos while showing limitations for others. Achieving a more generalized and robust solution across a wide range of video content remains a challenge.

– Lack of Real-world Testing: The algorithm's evaluation is typically performed in controlled experimental settings. Real-world scenarios may introduce additional complexities, such as varying network conditions and device capabilities, which could affect its performance differently.

– Scalability to Ultra High-Definition: While the algorithm demonstrates scalability to different video resolutions, its applicability to ultra high-definition (UHD) or 8K content may require further optimization and testing.

– Patent and Licensing Considerations: Depending on the specific implementation details and the use of proprietary video coding tools, the algorithm may be subject to patent and licensing restrictions, potentially limiting its adoption.

– Continuous Evolution of Video Coding Standards: Video coding standards, such as H.266/VVC, continue to evolve. Keeping the algorithm up-to-date with the latest standards and ensuring compatibility with future revisions may require ongoing development efforts.

– Addressing these limitations and further optimizing the algorithm for various use cases will be essential for its successful adoption and practical application in the field of video coding.

6. Conclusion. In summary, this research introduces a novel approach using a genetic algorithm-driven method tailored for intra coding within the H.266/VVC framework. This approach effectively orchestrates the utilization of coding tools and MTT partitions, leading to a reduction in encoding time while preserving video quality. Empirical findings underscore the efficacy of this algorithm, highlighting its viability for real-world integration into H.266/VVC encoders. The proposed algorithm strikes a harmonious equilibrium between encoding efficiency and video quality, positioning it as a promising solution for expeditious intra coding within H.266/VVC.

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ОСНОВАННЫЙ НА ГЕНЕТИЧЕСКОМ ПОДХОДЕ АЛГОРИТМ ВНУТРИКОДИРОВАНИЯ ДЛЯ H.266/VVC

Ибрагим И.Х., Абдаламир А.И., Хатиф Наджи А.З. **Основанный на генетическом подходе алгоритм внутрикодирования для H.266/VVC.**

Аннотация. Представлен генетический подход для оптимизации внутреннего кодирования в H.266/VVC. Предлагаемый алгоритм эффективно выбирает инструменты кодирования и многотипные древовидные разбиения (MTT) для достижения баланса между временем кодирования и качеством видео. Функция оценки пригодности, которая объединяет показатели восприятия и эффективности кодирования, используется для оценки качества каждого возможного решения. Результаты демонстрируют значительное сокращение времени кодирования без ущерба для качества видео. Предлагаемый алгоритм выбирает инструменты кодирования из набора доступных инструментов в H.266/VVC. Эти инструменты включают режимы внутреннего прогнозирования, единицы преобразования, параметры квантования и режимы энтропийного кодирования. Схема разбиения MTT включает четыре типа разбиений: квадродерево, двоичное дерево, троичное дерево и квадро-двоичное дерево. Показатели восприятия используются для оценки визуального качества закодированного видео. Показатели эффективности кодирования используются для оценки эффективности кодирования закодированного видео. Функция оценки пригодности объединяет показатели восприятия и показатели эффективности кодирования для оценки качества каждого возможного решения.

Ключевые слова: генетический алгоритм, H.266/VVC, внутреннее кодирование, инструменты кодирования, разделы MTD, время кодирования, качество видео.

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