Digital Video Watermarking with a Genetic Algorithm

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Abstract. Due to the explosion of data exchange on the Internet and the extensive use of digital media, it has been of intense interest to digital data owners in multimedia security and multimedia copyright protection. In this paper, a comprehensive approach for protecting and managing video copyrights with watermarking techniques is introduced. We propose a novel digital video watermarking scheme based on the scene change analysis and genetic algorithm. Robustness and fidelity are the essential requirements of a successful watermarking scheme. In pervious work, a robustness scene-based watermarking scheme is proposed. We focus on improving the fidelity of the scheme in this paper. The fidelity of the scheme is enhanced by applying a genetic algorithm, which optimizes the quality of the watermarked video. The effectiveness of this scheme is verified through a series of experiments.

1 Introduction

With the rapid growth of the Internet and multimedia systems in distributed environments, digital data owners can easily transfer multimedia documents across the Internet. Therefore, there is an increase in concern over copyright protection of digital contents [1, 2, 3, 4]. Traditionally, encryption and control access techniques were employed to protect the ownership of media. These techniques, however, do not protect against unauthorized copying after the media have been successfully transmitted and decrypted. Recently, watermark techniques are utilized to maintain the copyright [4, 5, 6, 7]. In this paper, we focus on engaging the digital watermarking techniques to protect digital multimedia's intellectual property right, and propose a new algorithm particularly for video watermarking purpose.

The problem of designing a feasible watermarking scheme can be viewed as an optimization problem with these conflicting goals: better robustness (watermark strength) and higher fidelity (media quality index). In our previous work [8], we proposed a scene-based watermarking scheme to improve the robustness of the scheme. However, the quality of the watermarked video should also be measured, which we called the fidelity of the watermarking scheme. In this paper, genetic algorithm (GA) is employed to enhance the fidelity of the proposed watermarking scheme.

The fidelity requirement often limits the strength of the embedded signals, which consequently constraints the robustness of a watermarking scheme against common or malicious manipulations. Existing watermarking schemes make reasonable trade-offs among the two requirements [9]. In other words, one can view the embedding process as a selection of feasible embedding points within an acceptable region in the space spanned by two mutually orthogonal axes representing the prescribed requirements, respectively shown in Figure 1. In this paper, a GA-based watermark fidelity enhancing method is proposed, which optimizes the performance towards the non-achievable region as indicated in Figure 1. The GA scheme is based on the scene-based watermarking scheme.

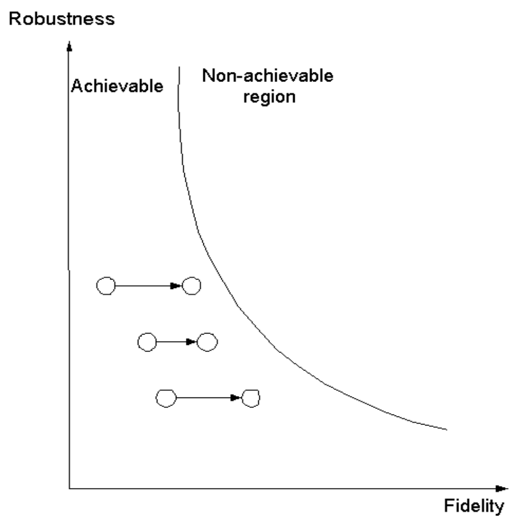

Fig. 1. The graph of two mutually orthogonal axes representing the robustness and fidelity of the watermarking scheme

2 Pervious Work

Video watermarking introduces a number of issues not present in image watermarking. Due to a large amount of data and inherent redundancies between frames, video signals are highly susceptible to piracy attacks, including frame averaging, frame dropping, frame swapping, statistical analysis, etc [4]. However, the currently proposed algorithms do not solve these problems effectively. We attack this problem by applying scene change detections and scrambled watermarks in a video.

The new watermarking scheme we propose is based on scene changes. Figure 2 shows an overview of our watermarking process. In our scheme, a video is taken as the input, and perform scene change detection by histogram difference method. Then each frame of the video is transformed to wavelet domain by DWT. At the same time, a watermark is also transformed to wavelet domain, and then decomposed into different parts according to the process shown in Figure 2. Afterwards, each part of the watermarks is embedded in the corresponding frames of different scenes in the original video with the embedding algorithm depicted in Figure 2. Finally, the video is transformed back to time domain.

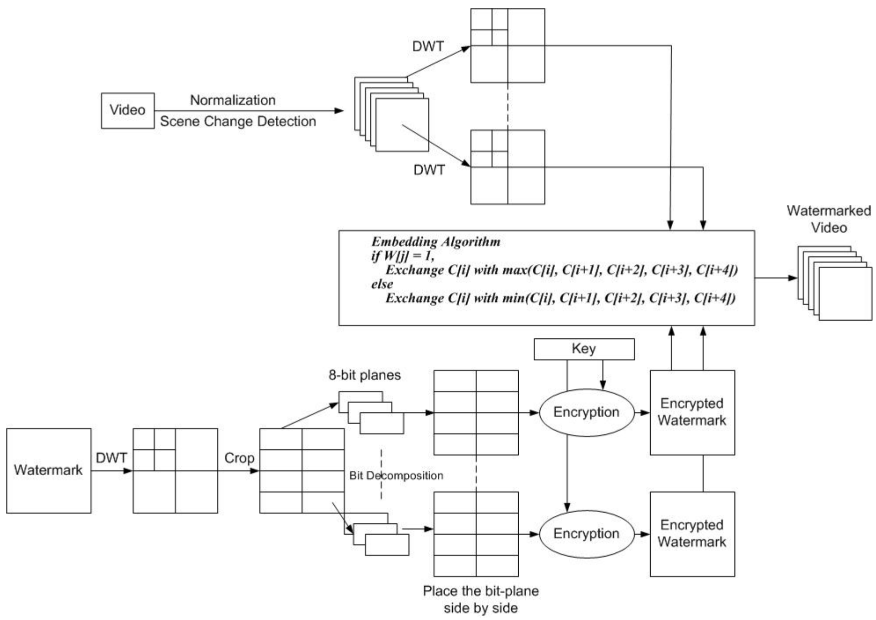

Fig. 2. Overview of the watermarking process

As applying a fixed image watermark to each frame in the video leads to the problem of maintaining statistical and perceptual invisibility [10], our scheme employs independent watermarks for successive but different scenes. However, applying independent watermarks to each frame also presents a problem if regions in each video frame remain little or no change frame after frame. These motionless regions may be statistically compared or averaged to remove the independent watermarks [11, 12]. Consequently, we use an identical watermark within each motionless scene. As shown in Figure 3 watermark m_1 is used for the first scene. When there is a scene change, another watermark m_3 is used for the next scene. The watermark for each scene can be chosen with a pseudo-random permutation such that only a legitimate watermark detector can reassemble the original watermark. With these mechanisms, the proposed method is robust against the attacks of frame dropping, averaging, swapping, and statistical analysis.

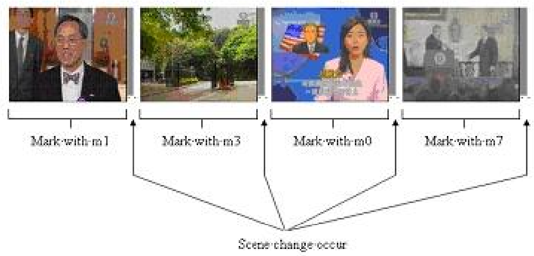

Fig. 3. Scene change detection

3 Genetic Algorithm based Watermarking Scheme

In the area of evolutionary computation, GA is an important optimization technique [9]. Here we employ this technique to optimize the performance of our proposed scheme. To model the problem as a GA problem, the fitness function, chromosome and GA operators should be defined. In GA-based optimizations, the problem to be addressed is defined as an objective function that indicates the fitness of any possible solution. According to the problem-specific constraints, a population of candidate is initialized, named as chromosome, which is a finite-length strings.

During practical GA-based optimization processes, three GA operators, reproduction, crossover, and mutation, are applied to the chromosomes repeatedly. Reproduction is a process in which individual chromosomes are copied according to their objective function values; that is, the fitness values. Chromosomes with higher fitness values have higher probability to contribute more offspring in the next generation. The objective function decides the probability of the chromosomes' survival or removal during the competition. Crossover is the procedure that pairs of chromosomes exchange portions of their genes to form new chromosomes, and consequently, new parameters other than the initial ones can be produced for evaluation. Mutation is the occasional random alternation of the value in some positions of chromosomes. Mutation can be regarded as a random walk through the parameter space. By sparingly using mutation, chromosomes with good performance but not obtainable by reproduction and crossover may also have the chance to be selected. These operators are used repeatedly to obtain successive generations of chromosomes [13].

Within a generation, only the chromosomes with the higher fitness values can survive. They will be passed as parent chromosomes to the next generation. After a number of generations, the chromosomes are optimized. We can obtain the near-optimal solutions of the modeled problems [9].

3.1 Problem Modeling

By applying the GA to the scene-based video watermarking scheme, the watermarked video quality is improved while still keeping the robustness of the watermark against image manipulation.

The embedding position of the different parts of a watermark within the video are simulated as chromosomes. Then several genetic-algorithmic operations are applied to optimize the video frame quality after embedding. In our experiments, we use image quality indicators, Mean Absolute Difference (MAD), to measure the objective function values during optimization.

We choose the watermark embedding positions within a video as our search space. That is, we search a scene into which a particular part of watermark is best to embed. Then we apply the genetic-algorithmic operators to find the best combination of the watermark and video scene. An illustrative diagram is shown in Figure 4. Assume a video consists eight scenes. The watermark is scrambled into eight parts and embedded into different scenes. The optimal combination of the watermark and the 0scene are shown in the chromosome.

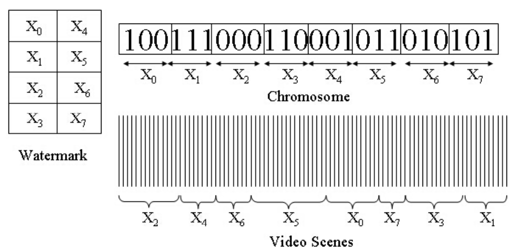

Fig. 4. A illustrative diagram for GA-based optimization process

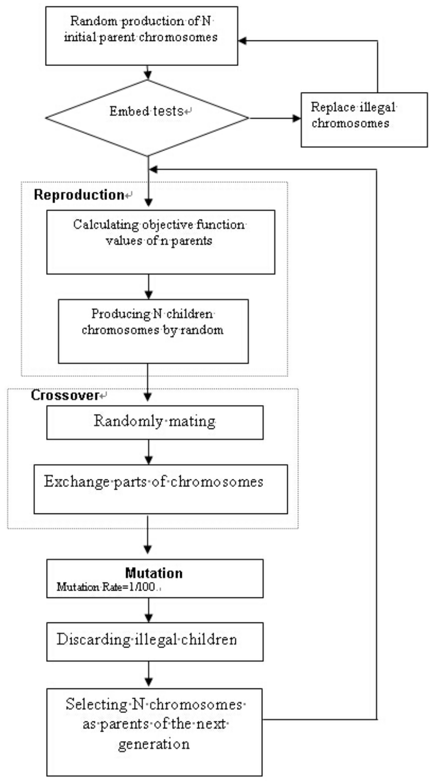

Fig. 5. The GA-based optimization process for part of watermark

By repeatedly applying the GA operations to each original video frame and watermark image, we can get near-optimal embedding positions for the original frame and the watermark images. Figure 5 shows the details of the GA-based optimization process for each video scene.

In the watermark scheme, the input video frames are transformed to frequency domain and the middle-frequency range coefficients of the watermark are modified according to the watermark. The basic idea is that the human eyes are sensitive to the low frequency noise and the quantization step of lossy compression may discard the high frequency components; therefore, the reasonable trade-off is to embed the watermark into the middle-frequency range of the video frames. I.e. watermarks are embedded by modifying the middle-frequency coefficients within each frame block of the original frame.

3.2 Chromosome Encoding

Assume we want to embed a part of the watermark image into one of the scenes in a video. The positions of the scenes are encoded as a chromosome. The number of scenes in the video is M and we can use log_2M bit to represent the positions of the scenes. The scene of the i^{th} watermark which is best to be embedded to X_i in the video can be defined as:

$$\{(X_i \mid 0 \le X_i \le (M-1), X_i \ne X_j, i \ne j \wedge M \ge 2\}\,, \tag{1}$$

The last two constraints of the above equation imply:

(1) There are at least two scene changes in the video; otherwise, the search space of the GA is 1 and no optimization can be done.

(2) In a video, the video frames that have been embedded should not be embedded again.

Figure 6 shows the sample chromosome which represents the positions of the watermark that should be embedded to. There are eight scene changes in the video and 3-bit number is needed to represent the position of the video scenes; therefore, a 24-bit chromosome representing the sequence of the video scene is employed.

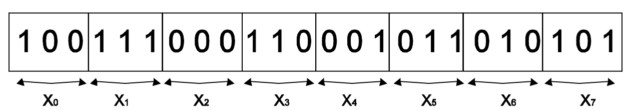

Fig. 6. A 24-bit chromosome represents the sequence of the scenes to embed

3.3 Genetic Operators

The initial chromosomes are generated with the above specification. Then, the genetic-algorithmic operators are applied to the chromosomes for optimization with the fitness function, which are reproduction, crossover, and mutation.

Fitness Function

The fitness function *f* is a measure of profit we need during optimization. This application of GA aims to improve the fidelity, i.e., the image quality, of the video frames. Therefore, the reciprocal of image similarity indicators (maximum absolute different MAD) is chosen to be the fitness function. The definition of fitness function *f* is then:

$$f = \frac{1}{\sum_{x=0}^{7}\sum_{y=0}^{7}\left|I'(x,y) - I(x,y)\right|}, \qquad (2)$$

Where *I'* and *I* are the intensity values of the same pixel position within a video frame after and before embedding, respectively.

After calculation of the fitness function value (defined in Equation 2) for each parent chromosome, we employ the biased-roulette-wheel method in GA [13] to generate *N* children. The basic idea is that the higher a parent chromosome's fitness function value is, the higher probability it has to contribute one or more offsprings in the next generation.

Reproduction

Reproduction is a process that the children chromosomes are generated according to the fitness function values of their parents.

Crossover

After *N* legal parent chromosomes and *M* children chromosomes are generated, crossover operator is applied to these children chromosomes. Firstly, the recently reproduced chromosomes are randomly mated in a pair. Then an integer position *p* between 1 and the chromosome length (*L)* minus 1 is selected at random for each pair where $p \leqq L-1$. Finally, each chromosome swaps all the bits between the location of $p+1$ and the chromosome length with its mate.

Mutation

After *N* legal parent chromosomes and *M* children chromosomes are generated, the last operator is mutation. Mutation is the random change of bit values with small probability within a chromosome. Mutation introduces some randomness into the optimization; thus, new combinations of watermarks and video scenes are generated. This increases the chance of approaching the optimal; otherwise, the optimization process is very slow. In our experiment, we use 0.05 as the mutation rate; namely, a bit may change polarity (i.e., take complement) at a probability of 0.05.

After performing all the GA operations, more children chromosomes may not satisfy the constraints of embedding positions. After a checking and discarding process, we can get M legal children chromosomes, where $M \leqq N$. From the $M+N$ chromosomes (M children and N parents), select N chromosomes with the larger fitness function values to be the next parent generations.

Repeat all the operations mentioned above until the number of generations specified has been done, and choose the best chromosome, i.e., the one with the largest fitness function value, to be the sequence of video scenes to be used. Figure 7 depicts the block diagram of the proposed watermarking algorithm with GA optimization.

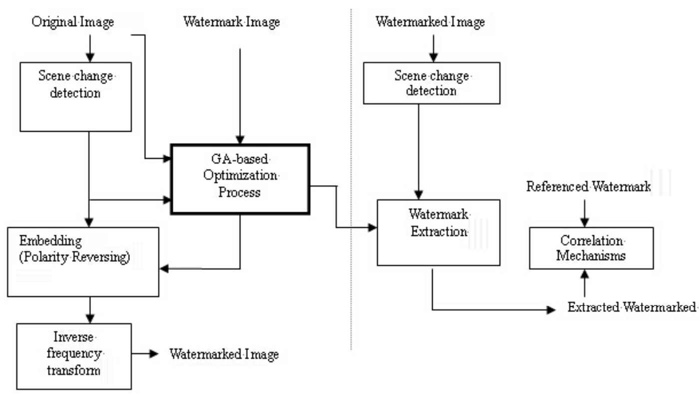

Fig. 7. The GA-based watermarking algorithm

The original video and the watermark are input to the system. Firstly, the scene change analysis is applied to the video and the watermark is preprocessed. Then, the GA-optimization process will find out the almost-optimal combination of watermarks and video scenes. The watermarks are embedded in to the video frames according to the result of the GA optimization. For detection phase, the GA information should be passed to the detector. The watermarked video is passed into the detection system, whereas the watermark is extracted with the GA information provided by the embedding phase. The original video frame, the watermarked video frame with scene-based watermarking scheme, and the watermarked video frame with GA-based watermarking scheme are shown in Figure 8. There is no significant perceptual difference between Figure 8 (b) and (c). However, the enhancement can be indicated by measuring with the quality index and the experimental results will be shown in the following section.

(a) (b) (c)

Fig. 8. Comparison between watermarked video with and without GA optimization a) Original video frame (b) Video frame watermarked with scene-based scheme (c) Video frame watermarked with GA-based scheme

4 Experimental Results

To implement the proposed watermarking scheme, the software VirtualDub [14] is employed. The GA-based watermarking scheme is implemented with the GAlib [15]. Moreover, evaluate the fidelity of the watermarking scheme, the peak signal-to-noise ratio (PSNR) and maximum absolute difference (MAD) is employed. We focus on evaluating the performance of the GA-based watermarking scheme. In the experiment, we demonstrate the fidelity enhancing effectiveness of the proposed optimization process.

PSNR is given by:

$$PSNR = 10\log_{10}\frac{255^2}{s_q^{\,2}}[dB], \tag{3}$$

where σ_q^2 is the mean square of the difference between the original video frame and the watermarked one [16].

MAD is given by:

$$MAD = \sum_{x=0}^{7}\sum_{y=0}^{7} | I'(x,y) - I(x,y) |, \tag{4}$$

where *I'* and *I* are the intensity values of the same pixel position within a video frame after and before embedding, respectively.

The performance of the GA-based video watermarking scheme is evaluated through several experiments with different numbers of generation in the GA-optimization process. Then, the quality of the video is evaluated with PSNR and MAD. The quality of the video watermarked by the scene-based watermarking scheme is also evaluated and compared with the GA-based scheme. In the experiment, two video clips are used. One of the video clips has 1526 frames of size 352×288 and it consists of 10 scene changes. Another video clip has 4236 frames of size 352×288 and it consists of

22 scene changes. The experiments are done on a desktop computer with Pentium 4 CPU 2.00GHz and 512MB RAM.

4.1 Parameter Setting

Table 1 shows the parameter setting for the GA-based video watermarking experiments. The population of the algorithm is chosen to be 100, the Mutation probability is 0.05 and the crossover probability is 0.9, which follow the setting in the GAlib [15]. The number of the generation is 1, 5, 10, 20, 40, 100, 200, 400 and 600. We stopped at 600 as the result converged after that number of generations. Table 2 shows the computation time of the GA-based scheme.

Table 1. Parameters Setting for GA-based experiment

Parameter	Value
Population	100
Mutation probability	0.05
Crossover probability	0.9
Score frequency	1
Flush frequency	25
Number of generations	In the experiment, we have used 0, 1, 5, 10, 20, 40, 100, 200, 400 and 600

Table 2. The computation time of theGA-based scheme

Number of Generation	Computational time of Video 1 (s)	Computational time of Video 2 (s)
0	50	141
5	62	179
10	80	234
20	103	289
40	124	354
100	156	423
200	185	534
400	226	620
600	259	702

4.2 Evaluate with PSNR

PSNR measures the signal to noise ratio of the watermarked video; thus, we can evaluate the video fidelity accordingly. From the graph depicted in Figure 9, it is clear that the GA-based algorithm successfully reduces the video frame distortion due to watermark embedding. As the number of generations increases, the improvement of video quality gradually approaches to a saturation value.

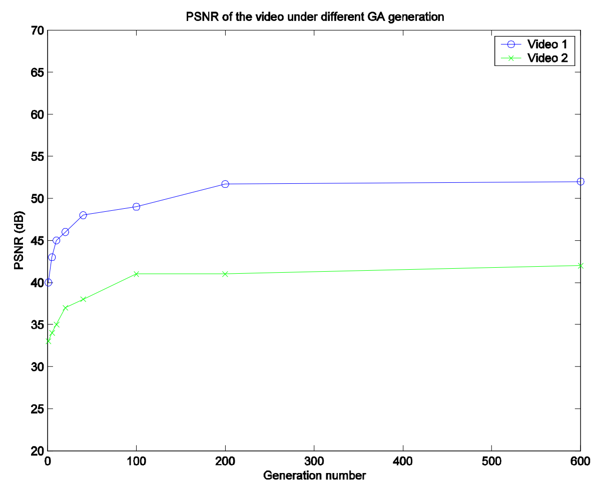

Fig. 9. PSNR of the video under different GA generations

Table 3 provides a comparison of PSNR with different watermarking schemes. The PSNR of the video is reduced to *3/4* after GA is applied in optimizing the fidelity of the scheme. It shows that the GA-based optimization effectively improves the performance of the scheme.

Table 3. PSNR comparison between different watermarking schemes

Watermarking scheme	PSNR of Video 1	PSNR of Video 2
Scene-based Watermarking scheme	40	33
GA-based watermarking scheme watermark scheme	52	42

4.3 Evaluate with MAD

MAD measures the difference between the original video and the watermarked video; consequently, we can evaluate the quality of the watermarked video. From the graph in Figure 10, we observe how the iterative generation numbers affect the optimizing performance. The MAD of the watermarked video is decreased with the GA generation number. The optimization performance saturates after about 200 generations. Therefore, the performance of the proposed GA-based watermarking scheme is converged to an optimal value.

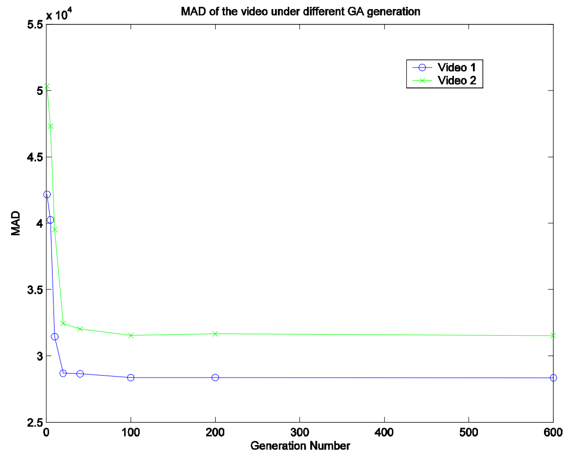

Fig. 10. MAD of the video under different GA generations

A comparison of MAD with different watermarking scheme is shown in Table 4. It illustrates the enhancing effectiveness of the GA-based watermarking scheme. The MAD of the video is reduced to *3/5* after GA is applied to optimize the fidelity of the scheme.

Table 4. PSNR comparison between different watermarking schemes

Watermarking scheme	MAD of Video 1	MAD of Video 2
Scene-based Watermarking scheme	42168	50325
GA-based watermarking scheme watermark scheme	28346	31546

From the experiments, we demonstrate that our proposed scheme enhances two prescribed watermarking requirements, robustness and fidelity. The robustness-enhancement provided by scene-based watermarking scheme and the fidelity-enhancement provided by the GA-based watermarking scheme are two important steps toward an optimal watermarking scheme.

Figure 11 shows a conceptual illustration. When there are two orthogonal axes, robustness and fidelity. The robustness is indicated by the strength of the watermark, and the fidelity can be represented by the quality index. Moreover, the curve represents the best robustness under the fidelity performance constraint. To optimize the performance of a watermarking scheme, we try to move the point towards the curve.

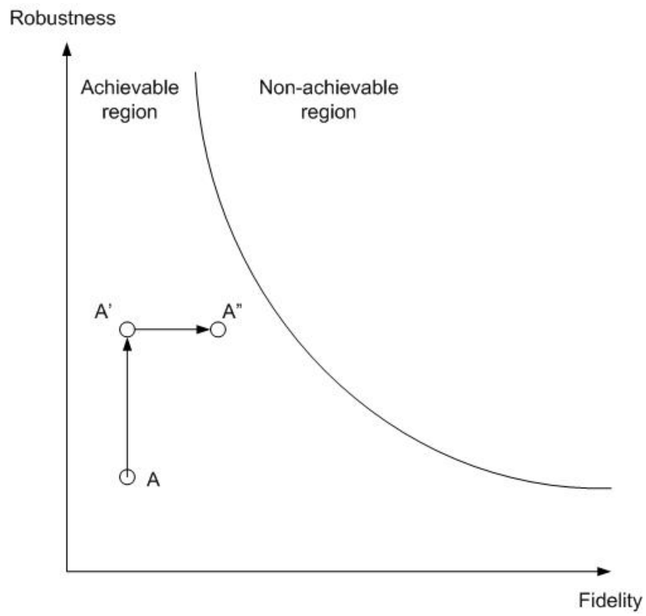

Fig. 11. A conceptual illustration on the performance of the proposed scheme

The point *A* represents the performance of a DWT-based watermarking scheme [17]. By applying the scene-based approaches, the robustness of the scheme is improved and moves the point to *A'* [8]. When the watermarking scheme is further enhanced by GA, i.e., to increase the fidelity of the scheme, the point moves along the fidelity axes. Thus, it moves towards *A"*. Consequently, our proposed scheme is approaching to the "optimal" embedding configuration.

5 Conclusion

Robustness and fidelity are two conflicting goals for a feasible watermarking scheme. This paper proposes an innovative Genetic Algorithm based video watermarking scheme. The fidelity of the original watermarking scheme is improved by applying genetic algorithm while the robustness of the scheme is preserved. We have also conducted a series of experiments to demonstrate its effectiveness.

Acknowledgement

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