A new real-time pattern selection algorithm for very low bit-rate video coding focusing on moving regions


For guidance on citations see FAQs

Link(s) to article on publisher's website:
http://dx.doi.org/doi:10.1109/ICASSP.2003.1199495

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online’s data policy on reuse of materials please consult the policies page.
A NEW REAL-TIME PATTERN SELECTION ALGORITHM FOR VERY LOW BIT-RATE VIDEO CODING FOCUSING ON MOVING REGIONS

Manoranjan Paul, Manzur Murshed, and Laurence Dooley

Gippsland School of Computing and Info. Tech., Monash University, Churchill Vic 3842, Australia
E-mail: {Manoranjan.Paul,Manzur.Murshed,Laurence.Dooley}@infotech.monash.edu.au

ABSTRACT

Very low bit-rate video coding, using regular shaped patterns to focus on moving regions in macroblocks, has gained significant attention recently. This paper presents a new real-time pattern selection (RTPS) algorithm using a large codebook of thirty two patterns. The algorithm uses a relevance measurement for all the patterns and a moving region, to eliminate a large number of irrelevant patterns prior to the actual best likelihood pattern selection procedure. Both theoretically and empirically it is proven that not only is the computational complexity of the new algorithm comparable to the contemporary algorithm that use a selection procedure. Both theoretically and empirically it is proven that not only is the computational complexity of the new algorithm comparable to the contemporary algorithm that use a selection procedure. It is also observed that using eight instead of four patterns improved the peak signal to noise ratio (PSNR) and coding efficiency significantly. A similar, but diminishing trend was also observed in [10][11], when the pattern codebook size was reduced from 32 to 16 patterns. In this paper, we present for the first time a new real-time, low bit-rate video coding algorithm focusing on moving regions using the 32-pattern codebook in Figure 1 and an extended parametric definition of MB classifications in [12].

Variable pattern selection approach is not readily applicable to real time video coding, as the coding process must be preceded by the selection of the \( \lambda \) best-matched pattern set. It has also been reported in [14] that using eight instead of four patterns improved the peak signal to noise ratio (PSNR) and coding efficiency significantly. A similar, but diminishing trend was also observed in [10][11], when the pattern codebook size was further extended. In this paper, we present for the first time a new real-time, low bit-rate video coding algorithm focusing on moving regions using the 32-pattern codebook in Figure 1 and an extended parametric definition of MB classifications in [12].

The computational complexity of this new approach is kept within the real time threshold by eliminating a large number of irrelevant patterns. A pattern is considered irrelevant to a moving region if the distance between their respective gravitational centers exceed a prescribed threshold. For example, if a moving region is well represented by pattern \( P_1 \), then patterns \( P_2, P_3, P_4 \), etc. may well be considered irrelevant for some thresholds. The exact condition for a pattern to be considered relevant is discussed in the next section.

1. INTRODUCTION

Reducing the transmission bit-rate while concomitantly retaining image quality is the most daunting challenge to overcome in the area of very low bit-rate video coding, e.g., H.26X standards [6,7,8,9]. Recently the MPEG-4 [5] video standard successfully introduced content-based coding, by dividing video frames into separate segments comprising a background and one or more moving objects. This is achieved by using a new real-time pattern selection (RTPS) algorithm using a large codebook of thirty two patterns. The algorithm uses a relevance measurement for all the patterns and a moving region, to eliminate a large number of irrelevant patterns prior to the actual best likelihood pattern selection procedure. Both theoretically and empirically it is proven that not only is the computational complexity of the new algorithm comparable to the contemporary algorithm that use a selection procedure. It is also observed that using eight instead of four patterns improved the peak signal to noise ratio (PSNR) and coding efficiency significantly. A similar, but diminishing trend was also observed in [10][11], when the pattern codebook size was reduced from 32 to 16 patterns. In this paper, we present for the first time a new real-time, low bit-rate video coding algorithm focusing on moving regions using the 32-pattern codebook in Figure 1 and an extended parametric definition of MB classifications in [12].

The computational complexity of this new approach is kept within the real time threshold by eliminating a large number of irrelevant patterns. A pattern is considered irrelevant to a moving region if the distance between their respective gravitational centers exceed a prescribed threshold. For example, if a moving region is well represented by pattern \( P_1 \), then patterns \( P_2, P_3, P_4 \), etc. may well be considered irrelevant for some thresholds. The exact condition for a pattern to be considered relevant is discussed in the next section.
Both theoretically and empirically it is proven that the computational complexity of the new RTPS algorithm is comparable to the original algorithm presented in [14]. However, experimental results also reveal that RTPS reduces the bit-rate by as much as 5.5% without losing any subjective quality (i.e. the change in PSNR is bounded by 0.5 dB).

This paper is organized as follows. The relevance of a particular pattern to a moving region is defined in Section 2. Section 3 presents the RTPS algorithm and the coding technique is further elaborated in Section 4. In Section 5, the computational complexity of the algorithm is analyzed and compared with that of the algorithm in [14]. Some experimental results are presented in Section 6, while Section 7 concludes the paper.

2. PATTERN RELEVANCE MEASURE

Let $C_k(x, y)$ and $R_k(x, y)$, $0 \leq x, y \leq 15$, denote the $k$th macroblock of the current and reference frames respectively, where the frame dimension is $W$ pixels x $H$ lines. The moving region $M_k(x, y)$ in the $k$th macroblock of the current frame is obtained as follows:

$$M_k(x, y) = T(C_k(x, y) \cdot B - R_k(x, y) \cdot B)$$

(1)

where $B$, of size 3x3, is the structuring element of a morphological closing operation $\circ$ [2][9]. $|v|$ is the absolute value of $v, T(v) = 1$ if $v > 2$ or 0 otherwise, and $0 \leq x, y \leq 15$, and $0 \leq k < W/16 \times H/16$.

Let $G(A)$ denote the gravitational center of the 16x16 matrix $A$ of bits (0 or 1), such that

$$G(A) = \left[ \frac{1}{256} \sum_{x=0}^{15} \sum_{y=0}^{15} x \cdot A(x, y), \frac{1}{256} \sum_{x=0}^{15} \sum_{y=0}^{15} y \cdot A(x, y) \right]$$

(2)

Lemma 1: Without losing any generality, it can be assumed that the gravitational center of a moving region will never be on the boundary of the macroblock.

Proof: A moving region can have its gravitational center on the boundary of the macroblock if and only if the region itself is part of either a horizontal or a vertical boundary line. Such a moving region should never be classified as an RMB.

Table 1: Values of $\eta_{max}(\eta_{min})$ and $\Delta(\eta_{min})$ for possible $\eta_{min}$ values

<table>
<thead>
<tr>
<th>$\eta_{min}$</th>
<th>$\eta_{max}(\eta_{min})$</th>
<th>$\Delta(\eta_{min})$</th>
<th>$\eta_{max}$</th>
<th>$\eta_{max}(\eta_{min})$</th>
<th>$\Delta(\eta_{min})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>11</td>
<td>5.81</td>
<td>15</td>
<td>32</td>
<td>12.72</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>6.00</td>
<td>17</td>
<td>32</td>
<td>13.00</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
<td>6.19</td>
<td>18</td>
<td>32</td>
<td>13.28</td>
</tr>
<tr>
<td>8</td>
<td>17</td>
<td>7.00</td>
<td>20</td>
<td>32</td>
<td>16.38</td>
</tr>
<tr>
<td>9</td>
<td>26</td>
<td>8.19</td>
<td>22</td>
<td>32</td>
<td>17.44</td>
</tr>
<tr>
<td>10</td>
<td>27</td>
<td>8.44</td>
<td>24</td>
<td>32</td>
<td>18.81</td>
</tr>
<tr>
<td>11</td>
<td>31</td>
<td>9.38</td>
<td>26</td>
<td>32</td>
<td>19.10</td>
</tr>
<tr>
<td>12</td>
<td>32</td>
<td>10.28</td>
<td>28</td>
<td>32</td>
<td>20.19</td>
</tr>
<tr>
<td>13</td>
<td>32</td>
<td>10.61</td>
<td>31</td>
<td>32</td>
<td>21.00</td>
</tr>
<tr>
<td>14</td>
<td>32</td>
<td>11.44</td>
<td>32</td>
<td>32</td>
<td>21.44</td>
</tr>
</tbody>
</table>

Let the relevance of the $k$th macroblock with pattern $P_n$ be calculated as:

$$\nabla_{k,P_n} = \text{dist}(G(M_k), G(P_n))$$

(3)

using the Manhattan distance:

$$\text{dist}(a,b) = |x(a) - x(b)| + |y(a) - y(b)|$$

(4)

where, $x(\cdot)$ and $y(\cdot)$ denote the x- and y-coordinates respectively. Manhattan distance is preferred to Euclidian distance because of its reduced computational time.

Let $\Delta(\eta_{min})$ be the minimum value, which guarantees that for at least $\eta_{min}$ patterns, the relevance measure $\nabla_{k,P_n} \leq \Delta(\eta_{min})$ for any $k$. $\Delta(\eta_{min})$ can be calculated as follows:

$$\Delta(\eta_{min}) = \max_{1 \leq x,y \leq 14, 0 \leq n \leq 32} \eta_{min} \min\{\text{dist}((x,y), G(P_n))\}$$

(5)

In the above calculation, the gravitational center of all moving regions is assumed to be never on the border (see Lemma 1).

$$\Delta(\eta_{min})$$ also leads to an upper limit in the number of possible relevant patterns, calculated as follows:

$$\eta_{max}(\eta_{min}) = \max_{1 \leq x,y \leq 14, 0 \leq n \leq 32} \left\{ \begin{array}{ll}
1, & \text{if dist}((x,y), G(P_n)) \\
0, & \text{Otherwise}
\end{array} \right\} \leq \Delta(\eta_{min})$$

(6)

Figure 2: An example supporting the calculated values of $\eta_{max}(4) = 11$ and $\Delta(4) = 6$.

Pattern $P_n$ is considered to be relevant to the moving region in the $k$th macroblock if and only if $\nabla_{k,P_n} \leq \Delta(\eta_{min})$, for all $k$ and $n$. The average number of relevant patterns can be approximated by $(\eta_{min} + \eta_{max}(\eta_{min}))/2$. Values of $\eta_{max}(\eta_{min})$ and $\Delta(\eta_{min})$ for all possible $\eta_{min}$ values are given in Table 1. It is interesting to note that there exist some consecutive values of $\eta_{max}$ for which the same $\Delta(\eta_{min})$ value is obtained, e.g., $\Delta(3) = \Delta(4) = 6.00$. In such cases, only the maximum $\eta_{max}$ value is tabulated. Figure 2 clearly proves the validity of the aforementioned calculations, where each square represents an area bound by the...
Manhattan distance 6 from its center. If the gravitational center of a moving region is exactly the same as the center of the dotted square, there exist only four relevant patterns; while as many as eleven patterns can be relevant when the gravitational center of a moving region is exactly the same as the center of the solid square.

3. THE RTPS ALGORITHM

Let the likelihood of the kth macroblock with pattern Pk be calculated as

\[ D_{k,n} = \frac{1}{256} \sum_{x=0}^{15} \sum_{y=0}^{15} | M_k(x,y) - P_k(x,y) | \]  

(7)

The kth macroblock is then classified as follows, for all k:

1) If \[ M_k < \delta \], then the kth macroblock is classified as an SMB.

2) Else if \[ M_k < \delta \] where \[ \delta = (64,96,128) \], and

\[ \min_{V_{x,y} \in \mathcal{A}(\eta_{max})} (D_{k,n}) < 0.25 \]  

(9)

then the kth macroblock is classified as an RMB whose moving region is represented by the first pattern \( P_i \) in the codebook where

\[ D_{k,i} = \min_{V_{x,y} \in \mathcal{A}(\eta_{max})} (D_{k,n}) \].

3) Else the block is classified as an AMB.

Besides using this extended definition of SMB, RMB, and AMB, the real-time pattern selection (RTPS) algorithm also calculates the \( D_{k,n} \) value partially, quadrant-by-quadrant. Let \( r \) be the speed-up factor of this technique compared to calculating the \( D_{k,n} \) value as a whole. It has been empirically found that \( r \) increases as \( \eta_{max} \) increases. This observation is presented in Figure 3 for the Miss America video sequence.

![Figure 3: Values of r for different \( \eta_{max} \) values on the Miss America video sequence.](image)

4. CODING TECHNIQUE

SMBs and the static regions of RMBs are skipped from coding and transmission as they can be obtained from the reference frame. For each AMB, as well as the moving region of each RMB, motion vector and residual errors are calculated using conventional block-based methods, with the obvious difference in having the shape of the blocks for the moving regions of RMBs as that of the best-match pattern, rather than being square.

To avoid multiple 8x8 blocks of DCT calculations for only 64 residual error values per moving region of RMB, these 64 values are rearranged into an 8x8 block. An inverse rearrangement is performed when decoding.

Pattern identification numbers are coded using variable length Huffman codes as given in Table II. These codes are obtained using the average pattern frequencies over a large number of standard and non-standard video sequences.

<table>
<thead>
<tr>
<th>Pattern ID number</th>
<th>( \eta_{max} ) number</th>
<th>variable length code</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 1010</td>
<td>90 010011</td>
<td>170 001100 250 111011</td>
</tr>
<tr>
<td>20 00101</td>
<td>10 01100</td>
<td>180 010010 260 001101</td>
</tr>
<tr>
<td>30 00011</td>
<td>110 01000</td>
<td>190 001101 270 010111</td>
</tr>
<tr>
<td>40 00000</td>
<td>120 01011</td>
<td>200 011111 280 0001000</td>
</tr>
<tr>
<td>50 011</td>
<td>130 001000</td>
<td>210 010001 290 111010</td>
</tr>
<tr>
<td>60 100</td>
<td>140 10110</td>
<td>220 101111 300 11100</td>
</tr>
<tr>
<td>70 110</td>
<td>150 111010</td>
<td>230 010100 310 001100</td>
</tr>
<tr>
<td>80 0011</td>
<td>160 11111</td>
<td>240 111101 320 010100</td>
</tr>
</tbody>
</table>

5. COMPUTATIONAL COMPLEXITY

Let \( \beta \) be the total number of candidate RMBs, meeting condition (8).

For each candidate RMB:

i) The moving region consists of \( (\delta + 4)/2 \) number of 1's on average. So, the average number of operations required to calculate the gravitational center of a moving region, based on (2), is

\[ \text{OP}(8x8) = 256 + (\delta + 4)/2 = \delta + 266 \].

ii) The relevance measure, in (3), takes \( 3 \times 32 = 96 \) operations in total for all 32 patterns.

iii) The likelihood measure in (7), is calculated on average for \((\eta_{min} + \eta_{max})(\eta_{max})/2\) patterns, each taking 512 operations.

So, the total number of operations required by the RTPS algorithm for pattern searching is:

\[ \text{OP}(\text{RTPS}) = \beta(\delta + 266) + 96 + (\eta_{min} + \eta_{max})(\eta_{max})/2 \times 512/\tau \]  

(10)

In contrast, for each candidate RMB, the algorithm in [14], computes only eight likelihood measurements (7) and so for the same video sequence, the number of operations required is:

\[ \text{OP}([14]) = \beta(8 \times 512) = 4096 \beta \]  

(11)

For \( \eta_{max} = 4 \), the average number of relevant patterns per candidate RMB becomes \((4 + 1)/2 = 7.5\), which is close to the pattern codebook size of algorithm [14]. To keep the PSNR comparable or even better, the RTPS algorithm must consider \( \eta_{min} \geq 4 \).

Assume that the RTPS algorithm is using \( \eta_{min} = 4 \) and \( \delta = 128 \). If \( \text{OP}(\text{RTPS}) \leq \text{OP}([14]) \), \( \tau \) must be \( \geq 1.065 \). Figure 4 shows that the average \( \tau \), for \( \eta_{min} = 4 \), is 1.10, which makes \( \text{OP}(\text{RTPS}) = 5981 \beta \approx \text{OP}([14]) \). It can, therefore, be claimed that the computational complexity of the RTPS algorithm is comparable to algorithm [14] while keeping the PSNR comparable.
pattern selection. However, for the sake of brevity, experimental results are presented using the first 100 frames of six standard video sequences. Table III shows that the RTPS algorithm outperforms both the algorithm in [14] and the H.263 standard in terms of lower bit-rate and higher PSNR for $\eta_{\text{min}} = 4$ and $\delta = 64$. However, the RTPS algorithm with $\eta_{\text{min}} = 4$ and $\delta = 128$ reduces the bit-rate by as much as 5.5% without losing any subjective quality.

7. CONCLUSIONS

Recently several studies on pattern representation of moving regions in block-based video motion estimation and compensation have been reported. In this paper, a new real-time pattern selection (RTPS) algorithm has been developed using a 32-pattern codebook. The RTPS algorithm uses a relevance measurement, in the form of the Manhattan distance between two gravitational centers, among all the patterns and a moving region to eliminate a large number of irrelevant patterns prior to the actual best likelihood pattern selection procedure. The algorithm uses a novel technique in guaranteeing lower and upper limit of relevant patterns. It has been established that not only the computational complexity of the RTPS algorithm is comparable to the previous algorithm in [14] but also the RTPS algorithm reduces the bit-rate by as much as 5.5%, while maintaining comparable subjective quality.

8. REFERENCES


<table>
<thead>
<tr>
<th>Video sequences</th>
<th>Video format</th>
<th>H.263 $\delta=64$</th>
<th>RTPS ($\eta_{\text{min}}=4$) $\delta=64$</th>
<th>RTPS ($\eta_{\text{min}}=4$) $\delta=96$</th>
<th>RTPS ($\eta_{\text{min}}=4$) $\delta=128$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bit-rate (kbps)</td>
<td>PSNR (dB)</td>
<td>Bit-rate (kbps)</td>
<td>PSNR (dB)</td>
<td>Bit-rate (kbps)</td>
</tr>
<tr>
<td>Miss America</td>
<td>QCIF (176 x 144)</td>
<td>53.8</td>
<td>44.8</td>
<td>53.2</td>
<td>45.0</td>
</tr>
<tr>
<td>Car phone</td>
<td>QCIF (176 x 144)</td>
<td>230.3</td>
<td>39.8</td>
<td>228.2</td>
<td>39.5</td>
</tr>
<tr>
<td>Foreman</td>
<td>QCIF (176 x 144)</td>
<td>290.1</td>
<td>38.3</td>
<td>288.2</td>
<td>37.7</td>
</tr>
<tr>
<td>Salesman</td>
<td>CIF (352 x 288)</td>
<td>725.9</td>
<td>40.0</td>
<td>716.1</td>
<td>40.1</td>
</tr>
<tr>
<td>Tennis</td>
<td>CIF (352 x 240)</td>
<td>1,630.4</td>
<td>36.6</td>
<td>1,614.5</td>
<td>36.3</td>
</tr>
<tr>
<td>Claire</td>
<td>CIF (352 x 288)</td>
<td>139.9</td>
<td>44.7</td>
<td>131.9</td>
<td>44.9</td>
</tr>
</tbody>
</table>