Video Compression Method for On-Board Systems of Construction Robots

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ABSTRACT: This paper describes the experiences relating to transmission of digital video information from an on-board video camera of inspection wall climbing robots. The decoder is modified in the proposed transmission scheme. The main difference with the conventional scheme is an interaction of the reference frame with the post-processing. If video coding and post-processing algorithms are available, proposed modifications can be implemented almost without additional expenses.
According to experiments, the method can increase efficiency of existing post-processing methods up to 40% in terms of the peak signal to noise ratio improvement. It is based on general video encoding principles and does not depend on particular implementation of the video codec and on post-processing implementation. The method can be used with standard video codecs like MPEG-1 or MPEG-4, and with variety of known post-processing algorithms. The main advantages of the proposed method are implementation simplicity and possibility to increase efficiency of the on-board inspection systems of autonomous mobile construction robots.

KEYWORDS: Mobile Construction Robot, Building Inspection, Digital Video Information, Post-Processing Algorithm.

1. INTRODUCTION

Some remote controlled construction operations require transmission of digital video information, for example, information from an on-board video camera of inspection wall climbing robots (see Figure 1).
There are many available standard video-compression methods, for example MPEG-1, MPEG-2, MPEG-4, DivX, VP3, and H.261. All of them are based on Discrete Cosine Transform (DCT) and suffer from compression artifacts. The most noticeable artifacts are blocking artifacts, which can be observed as coarse squares over the image.
Several approaches exist for the reduction of blocking artifacts. The most radical solution for this problem is overlapping transformations like MDCT [Vanhoucke] or LOT [Malvar] instead of DCT. The other proposed solutions are pre-processing [Panis] or post-processing schemes.
Known post-processing algorithms were not integrated with the codec introducing some loss of efficiency. Particularly, changes made by the post-processing do not propagate over the frame sequence. Every frame is processed independently. The efficiency can be increased by means of the integration of post-processing algorithms into the coding loop.
The decoder is modified in the proposed scheme. The main difference with the conventional scheme is an interaction of the reference frame with the post-processing. If video coding and post-processing algorithms are available, proposed modifications can be implemented almost without additional expenses.
According to experiments, the method can increase efficiency of existing post-processing methods up to 40% in terms of the peak signal to noise ratio improvement. It is based on general video encoding principles and does not depend on particular implementation of the video codec and on post-processing implementation. The method can be used with standard video codecs like MPEG-1 or MPEG-4, and with variety of known post-processing algorithms. The main advantages of the proposed method are implementation simplicity and a possibility to increase efficiency of the on-board inspection and navigation systems of autonomous mobile construction robots.

2. VIDEO COMPRESSION METHODS

A simplified typical DCT-based video encoder scheme is shown in Figure 2. It is assumed that a previously encoded frame or "reference" exists.
The frame to be encoded is divided by the square non-overlapping blocks. Encoding is performed for the each block separately. The most similar region (motion vector) is searched for every block in the reference frame. The difference between the block and the most similar region transformed to DCT domain is quantized and coded.
The difference between the source frame and the previously encoded reference frame is obtained as a result of motion compensation. The difference is quantized in DCT domain. Quantized DCT coefficients of the residual and motion compensation information are transmitted to the decoder. The reference frame is obtained as a reconstruction of the encoded frame.
A simplified video decoder scheme is shown in Figure 3. The decoder scheme is a reverse of the encoder scheme. The frame is decoded according to the motion compensation and residual information. After decoding, the frame can become a reference frame. Note, that if the post-processing is used in the decoder, it must not affect the reference frame. The reference frame must be identical both in the decoder and in the encoder. For the same reason, the encoder does not use an unmodified source frame as the reference frame. The reference frame is obtained after the reconstruction of the encoded frame.
The encoded frame contains motion compensation information and quantized DCT coefficients of the residual information. The difference between the frame to be decoded and the reference frame is obtained after dequantization of DCT coefficients and inverse DCT (IDCT). The decoded frame is obtained after adding the reconstructed residual frame to the previously decoded reference frame according to motion compensation information. The post-processing step is optional and does not interfere with the decoder.
The blocking artifacts occur after encoding at low bit rates due to a coarse quantization of the DCT coefficients. Visible blocks can not be aligned along rectangular grid because of the motion compensation.
The problem of blocking artifact removal has begun to draw attention since the JPEG compression was used. The most obvious method to remove them is to smooth block boundaries by a low-pass filter [Kim], [Yang]. Since an application of the low-pass filter to the whole image causes blurring effect, the adaptive filters are used. The filter parameters can be chosen according to initial assumptions and limitations.
By the real-time video processing, computational resources plays a critical role that makes some iterative methods [Yang] unfeasible for this task. The post-processing algorithm, suggested in [Kim] becomes a part of MPEG-4 video compression standard.

3. PROPOSED METHOD

The post-processing algorithms are not integrated with the codec. It reduces application efficiency. Particularly, changes made by the post-processing do not propagate over a frame sequence. Every frame is processed independently. The efficiency can be increased by means of integration of a post-processing algorithm into the coding loop.
In the proposed scheme, the decoder should be modified as shown in Figure 4. The difference with the conventional scheme is that the reference frame interacts with the post-processing. The post-processing is performed before obtaining the reference frame.
The encoder scheme should be modified too, because the encoder must have the same reference frame as the decoder. This scheme is shown in Figure 5. The reference frame is affected by the post-processing in the encoder structure.
If video coding and post-processing algorithms are available, the proposed modifications can be done almost without additional costs. The proposed scheme is suitable for specific applications where a video compression standard compatibility is not mandatory.
The suggested post-processing scheme was implemented by the connection of MPEG-2 video codec with a proprietary post-processing algorithm. A series of experiments was performed with the test sequence of 150 frames in QSIF format. The sequence was encoded with variable bit rates using standard GOP patterns (I, P and B frames). The post processing quality was measured according to an average PSNR measure. Results show that the proposed scheme increases the post-processing efficiency. For very low bit rates PSNR, the improvement is up to 40%.
The rate-distortion curve for the proposed algorithm along with curves for the codec without post-processing and the codec with conventional post-processing are shown in figure 6. Visual comparison results of the proposed method efficiency are clear from Figures 7-9.

Figure 7 shows original uncompressed picture of the cracks in the outer wall of the panel building. Figure 8 shows the same picture with blocking artifacts after MPEG-4 compression. Figure 9 shows the picture encoded according to the proposed method.
The proposed method removes blocking artifacts from the picture, without introducing blurring to significant parts of the picture. This facilitates perception of the picture by the operator, and reduces probability of incorrect identification of the construction surface quality.

4. CONCLUSIONS

The proposed method allows improving of the existing video blocking artifact removal efficiency for post-processing schemes. According to experimental results, the method can increase efficiency of the existing post-processing methods up to 40% in terms of PSNR (Peak Signal to Noise Ratio) improvement. The proposed method is based on general video encoding principles and does not depend on a particular implementation of the video codec and a post-processing implementation. The method can be used with standard video codecs, like MPEG1 or MPEG-4, and with a variety of known post-processing algorithms. The main advantage of the proposed method is implementation simplicity.

5. REFERENCES

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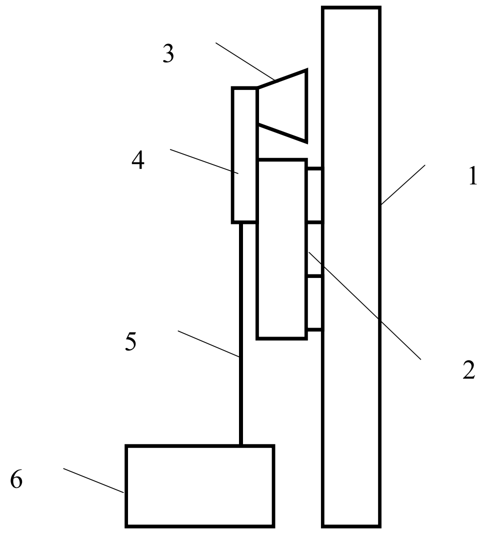

Figure 1. Diagram of building inspection
1 – wall, 2 – climbing robot, 3 – video camera, 4 – on-board control unit,
5 – cable, 6 – ground-based control unit

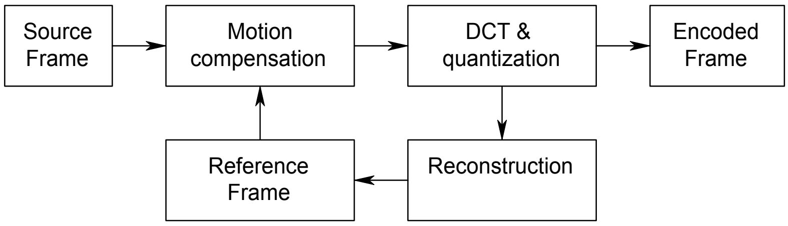

Figure 2. Simplified DCT-based video encoder structure

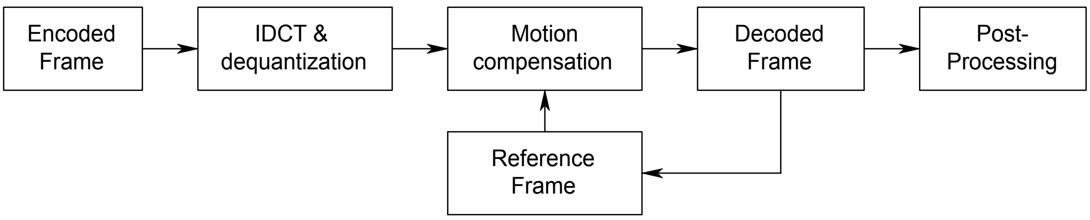

Figure 3. Simplified DCT-based video decoder structure

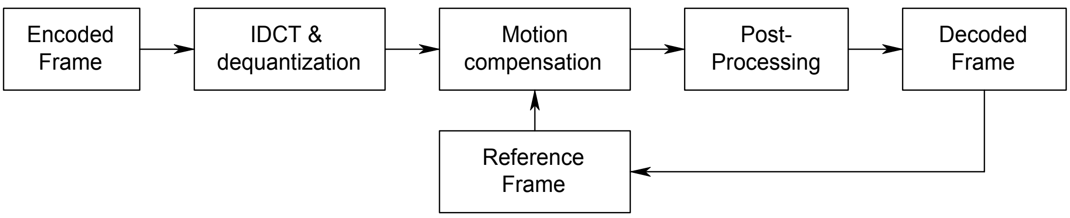

Figure 4. Proposed video decoder structure

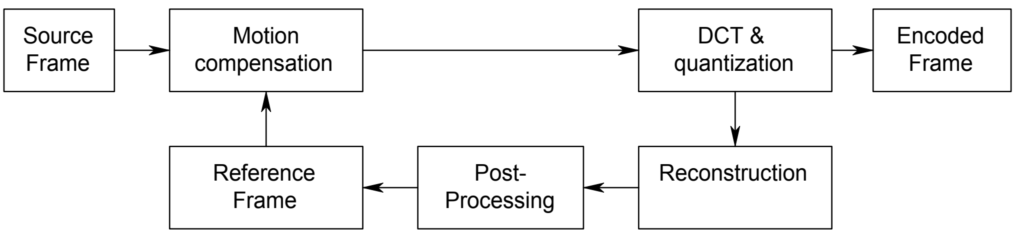

Figure 5. Proposed video encoder structure

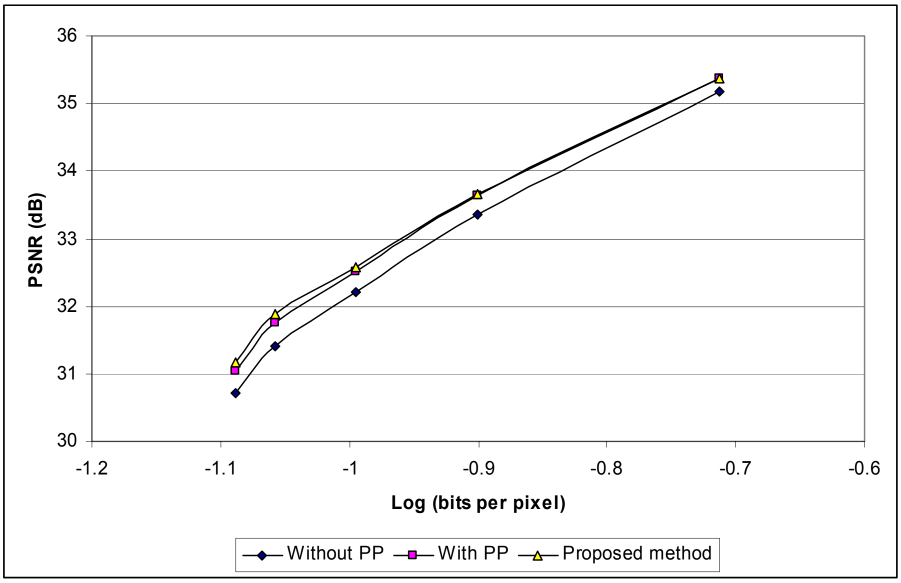

Figure 6. Rate-distortion curve for codec without post-processing (PP), codec with conventional post-processing and the proposed codec

Figure 7. Original frame

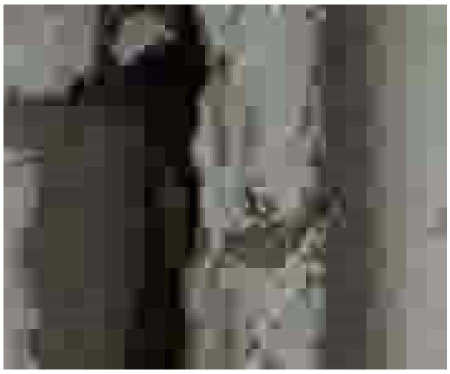

Figure 8. Frame, compressed at 0.09 bits per pixel without post-processing

Figure 9. Frame, compressed at 0.09 bits per pixel with proposed codec