ERROR-RESILIENCE PROFILING OF INTER-FRAME PREDICTION AT VVC ENCODERS FOR APPROXIMATION STORAGE EXPLOITATION

YASMIN SOUZA CAMARGO[1]; BRUNO ZATT[1];
DANIEL MUNARI VILCHEZ PALOMINO[1]; FELIPE MARTIN SAMPAIO[2]

[1] *Universidade Federal de Pelotas (UFPel) – {yasmin.sc, zatt, dpalomino}@inf.ufpel.edu.br*
[2] *Instituto Federal do Rio Grande do Sul (IFRS) – felipe.sampaio@farroupilha.ifrs.edu.br*

1. INTRODUCTION

Internet video traffic continues to surge, experiencing a 24% increase in usage in 2022 compared to the previous year, accounting for 65.93% of all internet data (SANDVINE, 2023). Addressing the challenge of managing this escalating video data, video compressors, known as encoders or codecs, play a crucial role in reducing video sizes. Newer standards like Versatile Video Coding (VVC), released in July 2020, offer impressive compression efficiency, reducing bit size by 50% compared to HEVC while maintaining the same visual quality (FRAUNHOFER, 2020). However, VVC demands significantly more computational resources, leading to higher energy consumption for applications using this codec.

The key challenge is to explore research opportunities to increase the energy efficiency of VVC video encoder implementations. Among the encoder steps, it is possible to emphasize inter-frame prediction, more specifically, the Motion Estimation (ME) modules, which represent up to 57% of the total VVC coding time, according to experiments carried out by Pakdaman et al. in 2020. Regarding the memory pressure required during VVC encoding, interframe prediction is responsible for 73-85% of all prediction steps, as reported by Cerveira et al. in 2020. To address this energy challenge, we explore approximate storage techniques, especially regarding memory infrastructure, which can lead to substantial energy savings. These techniques include lowering memory supply voltage to reduce energy usage in transmission and storage. However, this approach may introduce errors and degrade video quality (VIEGAS, 2016).

Hence, our research aims to assess resilience levels in VVC video encoders, particularly in memory regions of the inter-frame prediction module, where we explore approximate storage techniques. We aim to establish resilience profiles and identify suitable levels of coding efficiency loss in exchange for reduced energy consumption.

1.1. ADOPTED MEMORY MODEL FOR VVC INTER-FRAME PREDICTION

The inter-frame prediction in the VVC video encoder involves complex operations, tests, calculations, and memory access. This step focuses on predicting motion behavior between frames, employing three steps: Integer Motion Estimation (IME), Fractional Motion Estimation (FME), and Affine Motion Estimation (AME). This operation can be seen in Fig. 1, highlighting each of the memories that are most accessed (represented in blue). In IME, the encoder accesses the OrigSB memory, which stores the current frame being encoded and is used as a reference for finding the best prediction. RecoSB memory holds past and future reference frames (from L0 and L1 lists) that have already been encoded, reconstructed, and selected (GONÇALVES, 2021). IME heavily accesses RecoSB to find the most similar candidate block.In IME, the encoder accesses the OrigSB memory, which stores the current frame being encoded and is used as a reference for finding the best prediction. RecoSB memory holds past and future reference frames (from L0 and L1 lists) that have already been encoded, reconstructed, and selected (GONÇALVES, 2021). IME heavily accesses RecoSB to find the most similar candidate block. FME refines this search further by using fractional pixels for more accurate predictions. It generates samples using VVC-defined interpolation filters (FILHO et al., 2021) and stores data in FiltSB memory. The AME step predicts non-translational movements like rotation and zoom. AME involves complex operations and requires accessing PredSB memory to store local information (PARK; KANG, 2019).

This research evaluates VVC encoder resilience during errors in inter-frame prediction using an approximate storage model (Fig. 1), injecting errors into memory read/write operations. These errors impact IME, FME, and AME modules but do not affect frame reconstruction, ensuring alignment between encoding and decoding.

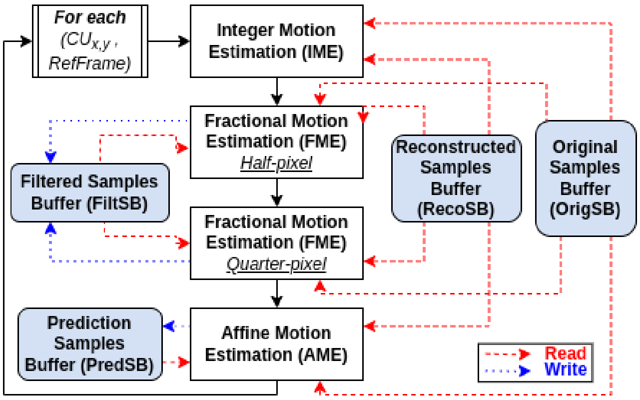

Figura 1. Adopted VVC inter-frame prediction memory model.

2. METHODOLOGY

We will assess memory resilience in the RecoSB, OrigSB, FiltSB, and PredSB modules. It is noteworthy that to insert the different error rates, both in reading and writing, a Dynamic Binary Instrumentation Tool (PinTool) tool was developed to be used with Intel Pin instrumentation tool, (LEVI, 2005). We examined error rates of 10^{-7}, 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}, and 0 (no loss).

Experiments were conducted using the Fraunhofer Versatile Video Encoder (VVenC) software, based on the VVC standard, with optimizations to reduce execution time. The medium profile was chosen, striking a balance between efficiency and time. VVC encoder runs covered the first 17 frames of four video sequences (BasketballDrill, BQMall, RaceHorses, and PartyScene) in class C (832x480 pixels). Each experiment was repeated 15 times for accuracy. Quantization Parameter (QP) values of 22, 27, 32, and 37 were used, following VVC evaluation recommendations.

After encoding, to facilitate data analysis, Python scripts were developed to extract necessary information, export data to a CSV file, calculate repetition averages, and generate result comparison graphs. Additionally, we calculated the BD-Rate, an objective metric representing rate-distortion efficiency losses observed in the experiments.

3. RESULTS AND DISCUSSIONS

Fig. 2 presents the results of approximate storage exploitation for inter-frame prediction-related memories: OrigSB, RecoSB, FiltSB, and PredSB using box plots. The charts also compare behavior across four coded video sequences: BasketballDrill, BQMall, RaceHorses, and PartyScene. Error rates ranged from 10^-7 to 10^-3 for both memory reading and writing operations.

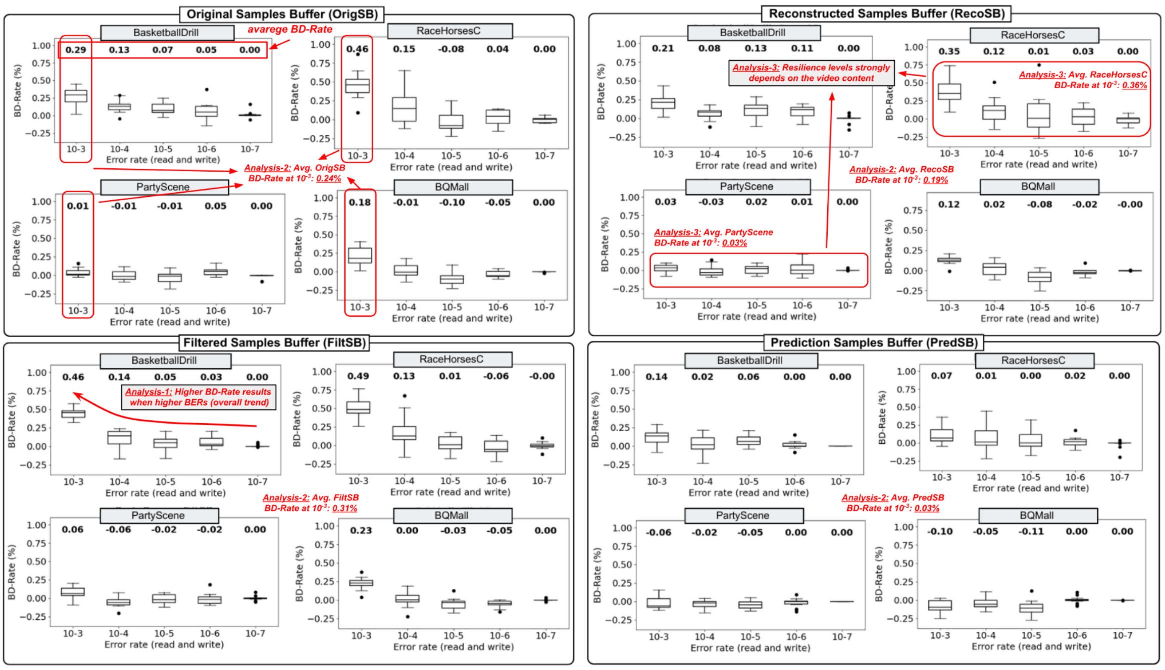

Figura 2. BD-Rate (%) results consideing error injection at each inter-frame prediction memory for each evaluated test sequence

<u>Analysis 1</u> (Impact of Error Rates): The analysis demonstrates a strong correlation between error rates and BD-Rate values. Higher error rates lead to increased BD-Rate values, signifying more significant losses in coding efficiency. Notably, this study focused on class C videos (832x480 pixels), resulting in relatively lower coding efficiency losses (BD-Rate results), even with an error rate of 10^-3. However, higher-resolution videos, such as HD1080p and 4K, may yield higher BD-Rate results.

<u>Analysis 2</u> (Memory Module Resilience):PredSB memory exhibited the lowest BD-Rate compared to other modules, with an average BD-Rate of 0.03% for an error rate of 10^-3. This suggests greater resilience to errors in PredSB. The AME prediction, specific to non-translational movements, is less utilized than IME and FME, resulting in fewer errors propagating to subsequent VVC encoder modules. For other modules, the average losses at an error rate of 10^-3 were 0.19%, 0.24%, and 0.31% for RecoSB, OrigSB, and FiltSB, respectively. Thus, FiltSB, responsible for storing FME interpolated samples, appeared the least resilient, followed by OrigSB and then RecoSB.

<u>Analysis 3</u> (Individual Video Characteristics): Analysis of each video individually reveals varying results, with some videos being more sensitive to specific encoding parameters than others. PartyScene exhibited an average BD-Rate of 0.03% at an error rate of 10^-3, while RaceHorses and BasketballDrill had rates of 0.36% and 0.26%, respectively. These variations are expected due to differing video characteristics, such as textures and motion properties, influencing coding approaches. For example, PartyScene may rely more on intra-frame prediction, leading to lower BD-Rate rates, while others predominantly employ inter-frame prediction, justifying higher rates

4. CONCLUSIONS

This study conducted an initial evaluation of resilience profiles within the VVC video encoder's inter-frame prediction module, with a specific focus on approximate storage techniques. We examined error tolerance levels in terms of coding efficiency losses (using the BD-Rate metric) when errors were introduced in reading and writing operations within four memory regions: RecoSB, FiltSB, OrigSB, and PredSB. The analysis revealed the potential for introducing errors during the coding process, with values remaining significantly low, resulting in no more than a 0.9% increase in BD-Rate. This suggests the possibility of reducing energy consumption. However, it's important to note that this work is in its early stages, and a comprehensive assessment of energy savings has not been conducted. Future work will include investigating the magnitude of these savings. Additionally, deeper analyses will be conducted on each memory and encoded video to obtain detailed resilience profiles. This will enable us to effectively utilize approximate storage techniques and assess their impact on reducing energy consumption in VVC codecs.

5. REFERÊNCIAS BIBLIOGRÁFICAS

BITMOVIN INC. **Bitmovin's 6th annual video developer report 2022**. 2022.

Cerveira, A., Agostini, L., Zatt, B., & Sampaio, F. (2020). **Memory profiling of H.266 Versatile Video Coding standard**. In 2020 27th IEEE International Conference on Electronics, Circuits and Systems (ICECS) (pp. 1–4).

FRAUNHOFER INSTITUTE FOR TELECOMMUNICATIONS. **Fraunhofer hhi is proud to present the new state-of-the-art in global video coding: H.266/vvc brings video transmission to new speed**. Julho de 2020.

GONÇALVES, P. H. R. **Um esquema rápido baseado em aprendizado de máquina para a predição interquadros do codificador de vídeo VVC**. Tese de mestrado, Universidade Federal de Pelotas, 2021.

LEVI, O. PIN: **A dynamic binary instrumentation tool**. Relatório técnico, Intel Corporation, 2005.

Pakdaman, F., Adelimanesh, M. A., Gabbouj, M., & Hashemi, M. R. (2020). **Complexity analysis of next-generation VVC encoding and decoding**. In 2020 IEEE International Conference on Image Processing (ICIP) (pp. 3134–3138).

PARK, S.-H., & KANG, J.-W. **Fast affine motion estimation for versatile video coding (VVC) encoding**. IEEE Access, 7, 158075–158084, 2019.

FILHO, V. R., MONTEIRO, M., SEIDEL, I., GRELLERT, M., & GÜNTZEL, J. L. **Hardware-friendly search patterns for the versatile video coding fractional motion estimation**. Em 2021 IEEE 23rd International Workshop on Multimedia Signal Processing (MMSP), 1–6, 2021.

SANDVINE. **Global internet phenomena**. Janeiro de 2023.

VIEGAS, T. G. **Técnicas de computação aproximada para implementação de filtros FIR**. Mestrado em engenharia elétrica e de computadores, Instituto Superior Técnico da Universidade de Lisboa, Portugal, 2016.