INTERFRAME-DEPENDENT RATE-QP-DISTORTION MODEL FOR VIDEO CODING AND TRANSMISSION

Mourad AKLOUF, Marc LENY, Michel KIEFFER, Frédéric DUFAUX

Université Paris-Saclay, CNRS, CentraleSupélec, Laboratoire des Signaux et Systèmes, F-91192 Gif-sur-Yvette
EKTACOM, F-91940 Les Ulis

{*mourad.aklouf, michel.kieffer, frederic.dufaux*}*@l2s.centralesupelec.fr, mleny@ektacom.com*

IEEE ICIP 19-22 September 2021

EKTACOM L'EXPERTISE VIDÉO NUMÉRIQUE

L2S cnrs CentraleSupélec UNIVERSITÉ PARIS SUD Comprendre le monde, construire l'avenir

Context - Motivation

Rate control is crucial to meet strict rate constraints in Ultra-low latency live streaming.

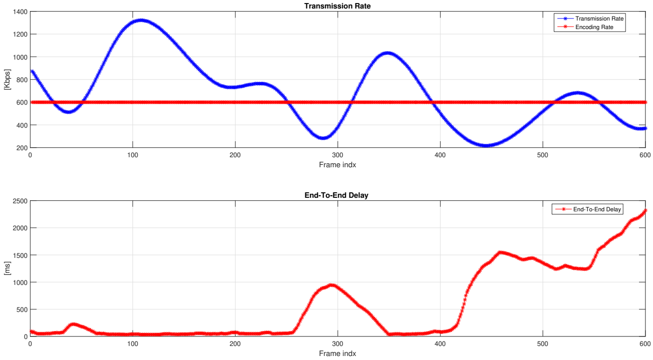
remote surgery

remote driving

sport events

Context - Motivation

Evolution of the end-to-end delay for video sequence encoding in 600kbps.



The mismatch between the encoding rate and available bandwidth may lead to an increase of the delay.

Context - Motivation

Excellent match between encoding rate and transmission rates requires
a frame-level model of encoding rate as a function of the quantization parameter.

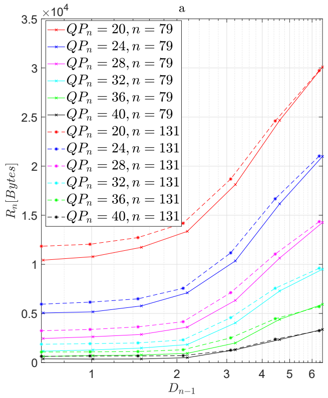
We propose a new model of the relation between R_n and QP_n depending on the Mean Square Error (MSE) distortion D_{n-1} for the reference frame n.

Inter-Dependent R-(QP,D) Model

For frame n, R_n depends on QP_n and D_{n-1}.

For a given QP_n, R_n increases :

- slowly when D_{n-1} is small,
- fast when D_{n-1} is large.



R_n for the frames $n = 79$ and 131 of *ParkScene* as a function of D_{n-1} for different values of QP_n.

Inter-Dependent R-(QP,D) Model

We propose the following R-(QP,D) model:

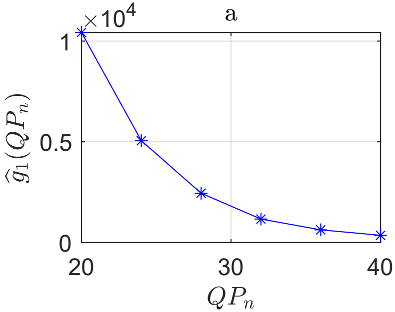
$$R_n\left(QP_n, D_{n-1}\right) = g_1\left(QP_n\right) + g_2\left(QP_n\right)\left(\tanh\left(g_3\left(QP_n\right)\log(D_{n-1}) - g_4\left(QP_n\right)\right) + 1\right), \qquad (1)$$

where,

- $R_n(QP_n, D_{n-1}) = g_1(QP_n)$ when D_{n-1} is very small.
- $R_n(QP_n, D_{n-1}) = g_2\left(QP_n\right)\left(\tanh\left(g_3\left(QP_n\right)\log(D_{n-1}) - g_4\left(QP_n\right)\right) + 1\right)$ when D_{n-1} is very large.

Inter-Dependent R-(QP,D) Model.

$$g_1(QP_n) = p_1 \exp\left(-p_2 QP_n\right)$$

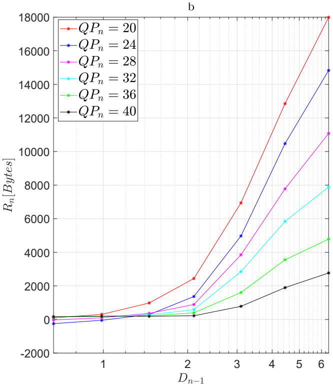


g_1 as a function of QP_n for frame 79 of ParkScene.

Inter-Dependent R-(QP,D) Model.

$$R_n^0\left(QP_n, D_{n-1}\right) = R_n\left(QP_n, D_{n-1}\right) - g_1\left(QP_n\right)$$
$$= g_2\left(QP_n\right)\left(\tanh\left(g_3\left(QP_n\right)\log(D_{n-1}) - g_4\left(QP_n\right)\right) + 1\right)$$

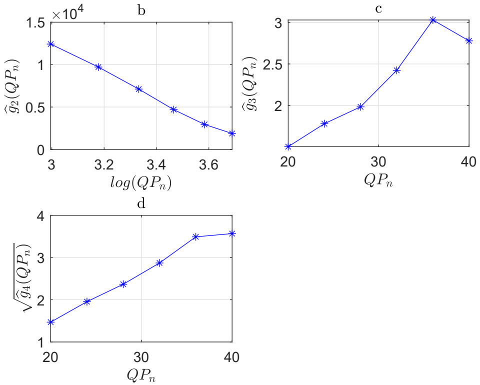
A least-squares estimation of $g2$, $g3$, and $g4$ is performed using R_n^0.



R_n^0 for frame $n = 79$ of *ParkScene* as a function of D_{n-1} for different values of QP_n.

Inter-Dependent R-(QP,D) Model.

- $g_2(QP_n) = p_3(-p_4 log(QP_n) + 1)$
- $g_3(QP_n) = p_5 QP_n$
- $g_4(QP_n) = (p_6 QP_n - p_7)^2$



$\widehat{g}_2$, $\widehat{g}_3$, and $\widehat{g}_4$ as a function of QP_n or $\log(QP_n)$ for frame 79 of *ParkScene*

Inter-Dependent R-(QP,D) Model.

In summary :

$$R_n\left(QP_n, D_{n-1}\right) = g_1\left(QP_n\right) + g_2\left(QP_n\right)\left(\tanh\left(g_3\left(QP_n\right)\log(D_{n-1}) - g_4\left(QP_n\right)\right) + 1\right) \qquad (9)$$

with,

$$g_1(QP_n) = p_1 \exp\left(-p_2 QP_n\right)$$

$$g_2(QP_n) = p_3(-p_4 log(QP_n) + 1)$$

$$g_3(QP_n) = p_5 QP_n$$

$$g_4(QP_n) = (p_6 QP_n - p_7)^2$$

Performance Evaluation

The proposed model is compared to models (1) , (2) and (3), **used at a frame level**.

Choi et al.[1]:

$$R_k = M \cdot N \cdot MAD_k \cdot \left(\frac{p_1}{Q_k^2} + \frac{p_2}{Q_k} \right) \tag{1}$$

Ma et al.[2], Li et al.[3]:

$$R_k = p_1 \frac{SAD_k}{Q_k} + p_2 \tag{2}$$

Yang et al.[4]:

$$R_k = p_1 \cdot M \cdot N \frac{\sigma_k^2}{Q_k^2} \tag{3}$$

---

[1] H. Choi, J. Yoo, J. Nam, *et al.*, "Pixel-wise unified rate-quantization model for multi-level rate control," *IEEE Journal in Signal Processing*, 2013.

[2] S. Ma, W. Gao, and Y. Lu, "Rate-distortion analysis for H.264/AVC video coding and its application to rate control," *IEEE transactions on circuits and systems*, 2005.

[3] Y. Li, H. Jia, P. Ma, *et al.*, "Inter-dependent rate-distortion modeling for video coding and its application to rate control,", IEEE, 2014.

[4] X. Yang, Y. Tan, and N. Ling, "Rate control for H.264 with two-step quantization parameter determination but single-pass encoding," *EURASIP Journal*, 2006.

Experimental Setup

- Tested sequences: Tango, Racehorses, ParkScene and Magnycours.
- Encoder: x265 software[5].
- Low delay configuration + Intra-refresh (cycle of one second).

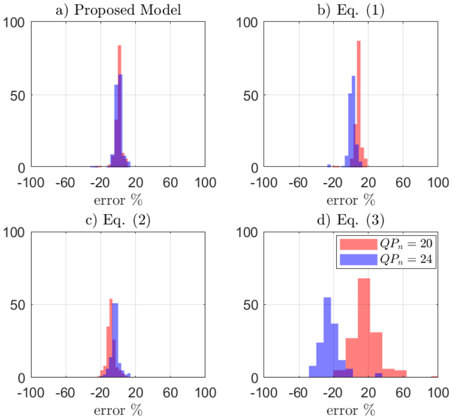
[5] MulticoreWare, *X265 software documentation*, https://x265.readthedocs.io/en/master/, 2020.

Experiment 1:
Coding at constant QP

Performance at high bitrates coding

The proposed model provides the best performance at high bitrates:

- In fig (a), Model (9) errors: -13.6% to 14%,
- In fig (b) and (c), Models (1) and (2) errors: -11% to 19%,
- In fig (d), Model (3) errors: -50% to 64%.

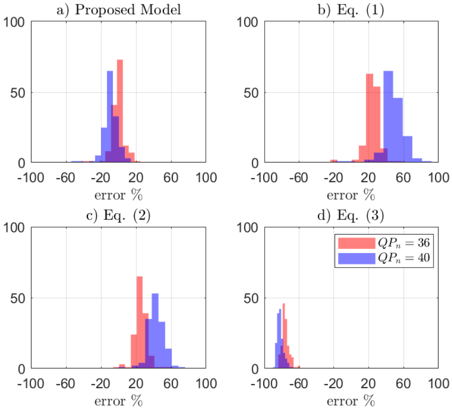


Histogram of prediction errors for *Tango* at high bitrates.

Performance at low bitrates coding

The proposed model significantly outperforms the three other models :

- In fig (a), (9) errors : -28.6% to 18.3%,
- In fig (b) and (c), Model (1) and (2) errors : 0% to 81% ,
- In fig (d), Model (3) errors : -90% to -58%.



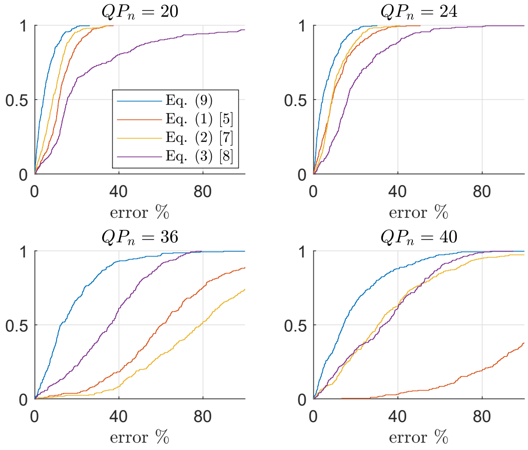
Histogram of prediction errors for *Tango* at low bitrates.

CDF of prediction errors - *Magnycours*

The proposed model achieves the lowest prediction error.

With QPn= 20: 90% of the prediction errors are less than:

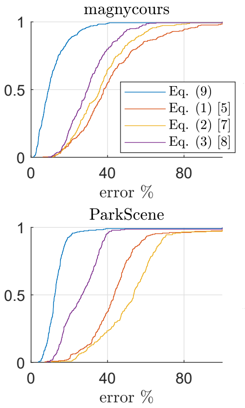
- 12.2% in Model (9).
- 16.7% and 22.6% in Model (1) and (2) respectively
- 51.8% in Model (3).



CDF of prediction errors for *Magnycours* sequence.

Average error CDF with constant QP

The proposed model achieves the best performance for all test sequences.

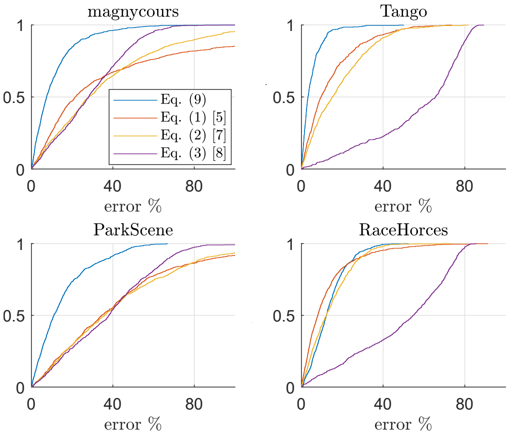


Average error CDF with constant QP for each sequence.

Experiment 2:
Coding at time-varying QPs

Performance with time-varying QPs

The proposed model outperforms the other ones for all sequences.



Error CDF with first-order Markov process variations of QP for each sequences.

Conclusion

- **Contribution** : A new model of the relation between R_n and QP_n depending on D_{n-1}.

- The proposed model outperforms the other models in both constant QP coding and variable QP coding.

- The gains with our model tend to be more significant at low bitrates.

- **Future work :** Integration of the proposed model in a rate control algorithm for Ultra low-latency video streaming.

Questions ?

Mourad AKLOUF
mourad.aklouf@l2s.centralesupelec.fr