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► **To cite this version:**

Achraf Ait-Beni-Ifit, Othmane Alaoui-Fdili, Patrick Corlay, François-Xavier Coudoux, Driss Aboutajdine. Profiling and Modelling of HEVC Intra Video Encoder's Energy Consumption for Next Generation WVSNS. Lecture Notes in Computer Science, 2017, Lecture Notes in Computer Science, 10299, pp.472-482. 10.1007/978-3-319-59647-1\_34 . hal-03565939

**HAL Id: hal-03565939**

<https://uphf.hal.science/hal-03565939v1>

Submitted on 12 Jun 2024

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# PROFILING AND MODELLING OF HEVC INTRA VIDEO ENCODER'S ENERGY CONSUMPTION FOR NEXT GENERATION WVSNS

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**Abstract.** Energy consumption is of main concern in the field of Wireless Video Sensor Networks (WVSNS) where energy resources are limited, consisting only in the battery of the sensor nodes that determines their lifetime. In this paper, we propose an empirical parametric model to predict the energy consumption of a High Efficiency Video Coding (HEVC) based video encoder in its intra-only mode, used in the context of the next generation WVSNS. Such model is of great interest to adapt the waste of energy of the encoding phase to the remaining energy budget of the node, while meeting the required video quality. The proposed model predicts the energy consumption, considering the adopted Quantization Parameter (QP) and the Frame Rate parameter (FR). A Raspberry Pi 2 card based video sensor node is used for modelling and validation, considering different configurations and spatial resolutions. The obtained results demonstrate that the proposed model describes well the occurred energy dissipation during the video encoding phase, with an average prediction error of 4.5%.

**Keywords:** Profiling and modelling, Energy consumption, video compression, H.265/HEVC, Next generation wireless video sensor network, Raspberry Pi 2

## 1 Introduction

Wireless sensor networks (WSNs) have attracted a wide range of disciplines, where close interactions with the physical world are essential. WSNs are new tools to capture information from the environment at a scale, both in time and space, previously hard to achieve [4]. Each node is battery powered and changing this component is, in general, undesirable and even impossible in some applications. Therefore, many efforts have been made in order to propose energy-efficient communication protocols in order to extend node's lifetime as much as possible [10, 7]. The availability of low-cost CMOS image sensors has enabled

the emergence of the field of next generation Wireless Video Sensor Networks (WVSNs) [15, 17]. Each node in a WVSN captures pictures or video sequences from the environment, processes it, then routes it towards the destination. Such nodes have allowed the development of new applications for the WVSNs, an example is given in [8] for Zoo video monitoring system called The Digital Zoo, funded by the EU regional development. The approach uses the WVSNs to collect multimedia information about animals and their surrounding.

The WVSN have introduced new research challenges to the field of WSN. In fact, the amount of data generated by an image sensor is much higher than other types of sensors. A QVGA image (320x240) at 12 bits per pixel will generate 115 200 bytes of data as presented in [8]. This exceeds by far the available RAM memory on a typical wireless sensor node. Moreover, a video sensor node spends its lifetime encoding and transmitting the video signal. According to [9], the video encoding phase consumes a significant amount of energy. Therefore, in order to extend the video node lifetime, the consumed energy during the video compression should be decreased, while maintaining the desired video quality. Consequently, a mathematical model is needed in order to predict the consumed energy by the video encoder. This model enables the node to adapt its configuration, considering its remaining energy as well as the targeted video quality, in order to extend its lifetime.

In this paper we propose an empirical energy consumption model for a High Efficiency Video Coding (H.265/HEVC) intra-only video encoder considering the QP and the FR parameters. The HEVC video coding standard is the last compression standard finalized in late 2012 and designed to achieve multiple goals, including coding efficiency, ease of transport system integration and data loss resilience, as well as implementability using parallel processing architectures. Furthermore, since the motion compensation and the motion estimation in inter GOP generate a significant energy consumption, we adopt the intra video coding for more energy efficiency. In addition, intra coding is essential for high quality mobile video communication and industrial video applications since it enhances video quality, prevents error propagation, and facilitates random access [18]. One can intuitively say that the energy decreases with the increasing of QP and when lowering FR. However, the main question that we are trying to answer is how does energy decrease when only intra-image coding is used? The answer will help to model the consumed energy by any HEVC intra-only mode based encoder, and will further allow us to optimize the consumed energy in WVSNs.

The rest of this paper is organized as follows: in Section 2, a brief overview of the previous works given on the subject is presented. In Section 3, the proposed mathematical model for energy consumption prediction during the video compression is derived. In Section 3, we validate the proposed model under different configurations. Finally, Section 5 concludes the paper.

## 2 Related Works

Several studies have contributed on energy consumption analysis of video-coding standards.

In [16], the authors analyse the rate-distortion-complexity of HEVC reference video codec (HM) and compare the results with AVC reference codec (JM). Profiling results show that the average software complexity ratios of HM and JM encoders are 3.2x in the All-intra case. This paper also reveals the bottlenecks of HM codec and provides implementation guidelines for future real-time HEVC codecs.

In [1], the authors propose a model to predict the energy consumption of a H.264/AVC intra-only based encoder designed for the WVSNs, with respect to the considered QP and FR values. In fact, in this paper, the authors compare the energy consumption of the intra-only mode against the inter mode (i.e. GOP IPPPP) and prove the energy efficiency of the first mode. Finally, the proposed model is applied on the encoder under different configurations (i.e. resolution, QP and FR). However, the authors perform the tests as simulations on a computer and not on an actual sensor node.

In [2], the authors present an overview of the complexity in both HEVC encoder and decoder and recommend to use the HM implementation of the HEVC standard. However, the authors do not propose a model for complexity behaviour in the HEVC encoder.

In [5], the authors propose a model that describes the energy consumption of the HEVC decoder for intra coded videos with a prediction error of 3.2%. However, we are interested by the encoding phase.

In [13], the authors propose the profiling of the HEVC standard using the Valgrind tool [14] to determine the cost of each function and instruction of the encoding phase. The results show that, in an HEVC encoding process, about 48% of the instructions are memory related and about 20% are arithmetic operations. Except that, the author did not propose a model of energy consumption in HEVC standard.

Finally in [12], the authors present an energy model for an intra-only HEVC video encoder. It estimates the energy consumed by the HEVC encoder, in a frame by frame basis, considering two factors: the QP and the spatial information of each frame. Experimental validation reports prediction errors that are, on average, below 10% for full HD videos and 5% for  $832 \times 480$  videos. However, the proposed analytic expression of the model remains complex.

## 3 The proposed model

The main purpose of this section is to find the analytic expression of  $f(\cdot)$ , defined as follows:

$$E(QP, FR) = f(QP, FR) \quad (1)$$

In order to find the appropriate analytic expression, we adopt the approach that is based on profiling the HEVC using Perf in a Raspberry Pi 2 (RPI2) Card.

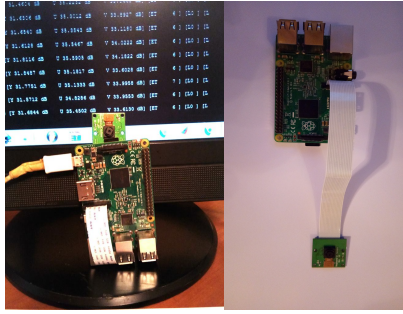


Fig. 1. Raspberry Pi 2 Card and the camera module

Fig. 1 shows the RPI2 card we used for testing with the camera module. Perf is a profiling tool dedicated to Linux 2.6+ systems. The Perf tool offers a rich set of commands to collect and analyse performance and trace data, especially "perf stat". An execution example of "perf stat" command is presented in Fig.2.

```
Performance counter stats for './TAppEncoderStatic -c in.cfg -c intra.cfg -q 10':
4667189,435610 task-clock (msec)          # 1,000 CPUs utilized
      2 565 context-switches             # 0,001 K/sec
      1 cpu-migrations                   # 0,000 K/sec
      22 180 page-faults                 # 0,005 K/sec
3 853 429 415 529 cycles                  # 0,826 GHz
<not supported> stalled-cycles-frontend
<not supported> stalled-cycles-backend
2 383 511 972 109 instructions            # 0,60 insns per cycle
174 163 875 700 branches                  # 37,317 M/sec
52 220 027 760 branch-misses              # 29,98% of all branches

4667,404334245 seconds time elapsed
```

Fig. 2. Execution example of "perf stat" on an encoding process

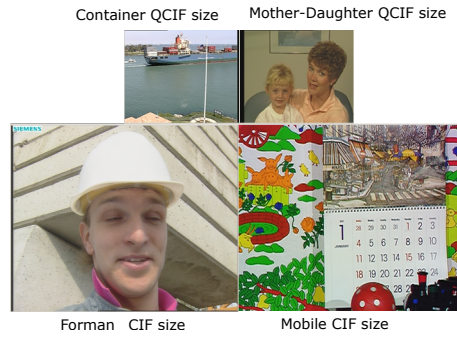
Such an approach will provide us an accurate overview of the number of the consumed clock cycles. Then, according to [3], the energy consumed during the video encoding could be approached by:

$$E(N) = N * C * V_{dd}^2 + V_{dd} * (I_0 e^{\frac{V_{dd}}{nV_T}} (\frac{N}{f})) \quad (2)$$

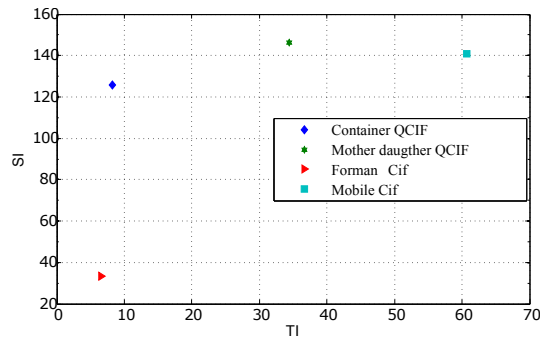
Where  $N$  is the number of clock cycles,  $C$  is the average capacitance switched per cycle,  $V_{dd}$  is the supply voltage,  $I_0$  is the leakage current,  $f$  is the clock speed,  $V_T$  is the thermal voltage and  $n$  a processor dependent constant.

In order to derive the appropriate model, extensive tests were carried out for energy measurements using several video sequences. The ITU-T [6] recommends for the selection of appropriate video test sequences to consider the spatial and temporal perceptual information of the scenes, noted in the following SI and TI respectively. In fact, these parameters reflect the compression difficulty as well as the level of impairment that is suffered when the scene is transmitted.

Furthermore, it is important to choose sequences that span a large portion of the spatial-temporal information domain.



**Fig. 3.** Illustration of the chosen video sequences of different resolutions and content features



**Fig. 4.** The TI-SI diagram

Fig.3 presents several sequences of different resolutions providing TI-SI pairs that cover several regions of the SI-TI domain. In fact, four video sequences were selected: Container and Mother-daughter in QCIF size, Foreman and Mobile in CIF size. As can be seen, the considered set of video sequences covers a large area, showing its TI-SI diversity. In fact, according to the Fig.4, this set includes video sequences representing contents with a moderate TI and SI ranging from low to high (i.e. Foreman and Mobile), while others represent contents with a moderate SI and TI ranging from low to high (i.e. Mother-daughter and Container).

### 3.1 Modelling the consumed energy as a function of QP

To achieve the H.265/HEVC profiling we have carried out several compression operations considering six values of QP ranging from 0 to 51 via the HM-11.0 implementation. Profiling is achieved through the Perf tool under RPI2 Card to estimate the total number of clock cycles. With the use of Perf, we managed to gather the exact number of cycles of each type of operation in all functions of HEVC (i.e. prediction, transformation, quantization and entropy coding). Fig.5

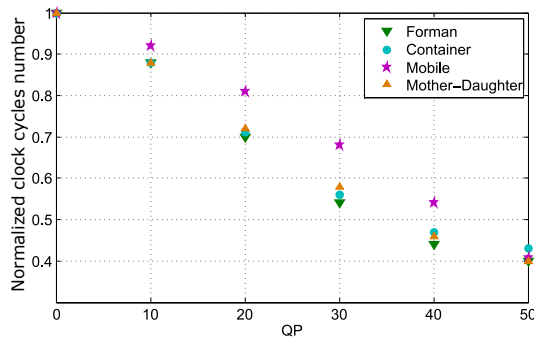


Fig. 5. Normalized number of clock cycles while varying QP

illustrates the behaviour of the normalized consumed cycles during the video compression of the tested video sequences. We can notice that the number of cycles, and hence the consumed energy, decreases when the QP is increased. This can be explained by when increasing the QP value, the quantization becomes more severe, generating macroblocks with more null coefficients. Having many null coefficients leads to the reduction of the complexity of the entropy encoding process.

Fig.5 shows the behaviour of a reduction factor dependent on QP, we call it  $\alpha(QP)$ . This factor decreases the maximal consumed energy  $E_{max}$ , which is reached at  $QP = 0$ . Furthermore,  $\alpha(QP)$  reaches its maximum value of 1 at  $QP = QP_{min} = 0$  and its minimum value at  $QP = QP_{max} = 51$ . Based on all the above mentioned arguments, we propose to model  $\alpha(\cdot)$  as follows:

$$\alpha(QP) = \exp(-a * QP) \tag{3}$$

Where  $a$  is a coefficient dependent on the content obtained by minimizing the Root Mean Squared Error (RMSE) between the measured and the predicted data. The corresponding value of  $a$  in Eq.3 for each sequence, is determined by curve fitting optimisation [11]. The results of this operation is reported by Fig.6. Points are the measured coefficients and the curves are the predicted ones by the proposed model of Eq.3. As can be seen, the proposed model describes well the behaviour of the measured coefficients.

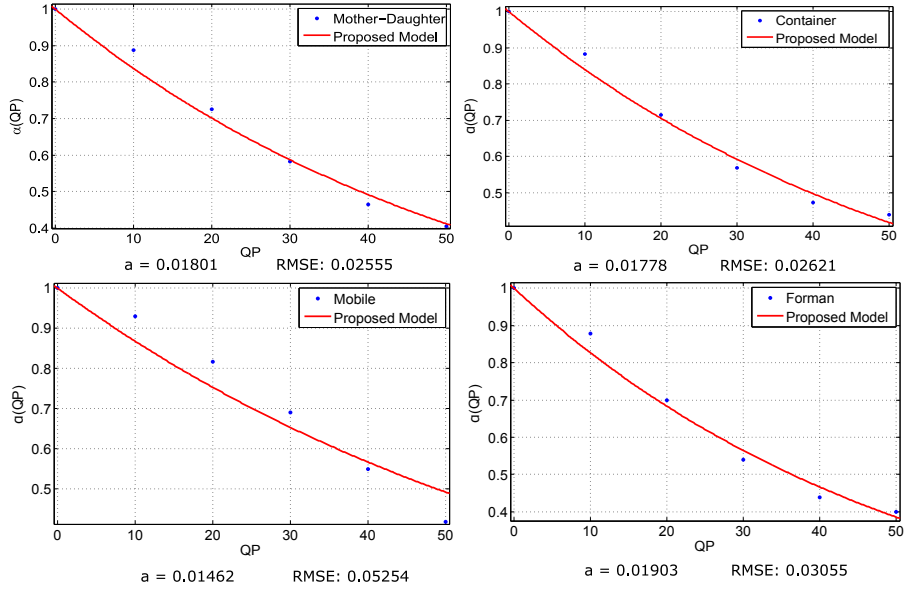


Fig. 6. Measured data and its approximation using the proposed model of Eq.3

### 3.2 Modelling the consumed energy as a function of FR

The FR parameter is the second factor that we consider to predict the energy consumption of our video encoder. We can change the FR in the HM implementation by varying the parameter named Frame Skip (FS). The relationship between these two parameters is given as follows:

$$FS = \left\lceil \frac{FR_{max}}{FR} \right\rceil - 1 \quad (4)$$

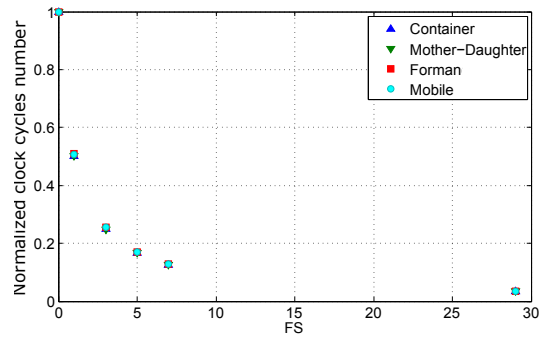


Fig. 7. Normalized number of clock cycles while varying FS

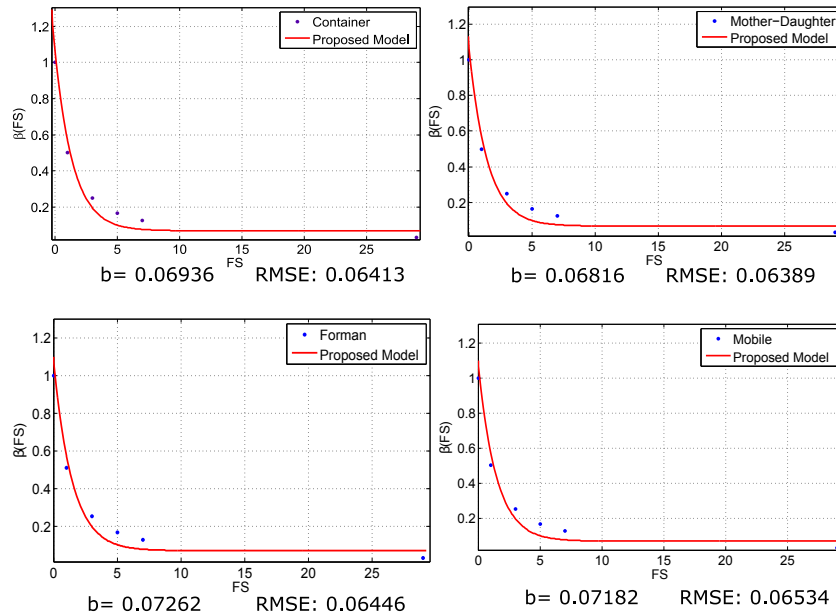


Fig. 7 represents the number of normalized clock cycles while varying the FS. As can be seen, energy decreases with the increasing of the FS, leading to the decreasing of the FR. This can obviously be explained by when reducing the FR, the FS is increased and hence less frames are encoded. Consequently, a considerable reduction of the consumed energy is observed. Note that the  $FR_{max}$  of the tested video sequences is 30 fps and using Eq.4 one can deduce the tested FRs. Also, we notice that the incrementation of the FS by one reduces the energy by about the half and so on, which is an obvious and expected behaviour.

Fig. 8 shows the behaviour of a reduction factor that is FS-dependent. We name it  $\beta(FS)$ . This factor actually reaches its maximum value of 1 at  $FS = FS_{min} = 0$  and quickly decreases toward its minimum value at  $FS = FS_{max} = 29$ . In addition, this factor does not attain the zero value since there is at least one frame to be encoded. Based on the above mentioned arguments we propose to model  $\beta(\cdot)$  as follows:

$$\beta(FS) = \frac{1}{2FS} + b \quad (5)$$

Where  $b$  is a content dependent parameter obtained by minimizing the RMSE between the measured and the predicted data. As shown in Fig.8, the proposed model in Eq.5 can model the behaviour of the reduction factor  $\beta(FS)$  accurately.



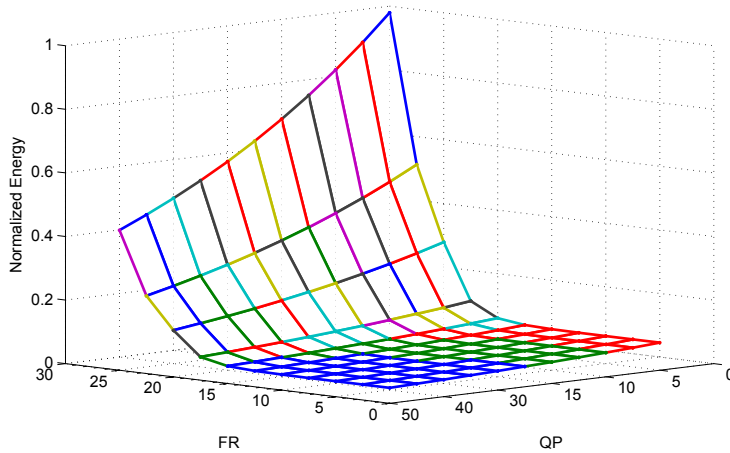
**Fig. 8.** Measured data and its approximation using the proposed model of Eq.5

### 3.3 The global model

The energy consumed is reduced by a QP-dependent reduction factor and an FR-dependent reduction factor. Therefore we propose the following formulation of the global model:

$$E(QP, FR) = E_{max} \times \alpha(QP) \times \beta\left(\left\lceil \frac{FR_{max}}{FR} \right\rceil - 1\right) \quad (6)$$

$E_{max}$  is the maximum value of energy, reached for the pair  $(QP_{min}, FR_{max})$ . Summarizing, we expose in Fig. 9 the overall behaviour of the normalized video encoding energy consumption while varying QP and FR, using the model of Eq. 6.



**Fig. 9.** Illustration of the normalized energy consumption considering QP and FR using the model of Eq. 6

## 4 Model Application

In this section, we apply the proposed model on seven other sequences using seven different values of QP and FR. The model parameters  $a$  and  $b$  values of each sequence are set, as a first approach in this paper, to the average values of  $a = 0.01736$  and  $b = 0.07049$ . We report in Table.1 the Measured Value (MV), the Predicted Value (PV) and the Prediction Error (PE) for each sequence and considered configuration. MV is obtained by normalizing the measured number of clock cycles for each configuration in terms of QP and FR. PV is obtained using the proposed model in Eq.6, for each of the pairs (QP,FR) listed in Table.1.

As can be seen, the PE varies from 1.8% for the Basketball-drill sequence to 10% for the Bosphorus sequence, even if the the model parameters values are not the optimal ones. As shown in Table.1, the average prediction error of the proposed model in Eq.6 is about 4.5%.

**Table 1.** The tests results considering different sequences, of different resolutions under different configurations

Seq	Res	QP	FR	MV	PV	PE
Bus	QCIF	15	1	0,038	0,059	2%
Hall	QCIF	25	7.5	0.126	0.158	3.2%
Soccer	QCIF	25	3.75	0,050	0.101	5%
News	CIF	15	30	0,368	0.439	7%
Tennis	CIF	40	6	0,075	0.050	2.5%
Basketball	832 × 480	30	3.75	0.046	0.064	1.8%
Bosphorus	Full HD	15	30	0.711	0.818	10%

## 5 Conclusion

In this paper we have proposed an empirical parametric model to predict the energy consumed by the encoding phase, considering the HEVC intra-only video encoding standard, used in an energy constrained context such as the WWSN. Specifically, we have demonstrated that this energy, given a configuration of (QP,FR), could be approximated by the maximum consumed energy value undergoing QP-dependent then FR-dependent reductions. Finally, the proposed model was validated and applied on different sequences of different resolutions and considering different configurations. This model can be even better by automating the selection of the models parameters  $a$  and  $b$ ; this is actually our ongoing work.

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