Accuracy of Low Power Estimation for Embedded Application

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Abstract
Dealing with power is rapidly becoming one of the most demanding issues in digital system design. This situation is aggravated by the increasing demand for portable systems. Several consumption estimations tools have been proposed with different accuracy. Moreover, a minority of tools estimate the global architecture consumption with details about accuracy. In this paper, we propose a low power design methodology at a high level in order to estimate the energetic performance, and to compute the expected accuracy. The estimation frameworks and the mathematic approach are presented in this paper. The accuracy is used to provide a confidence interval to the estimated consumption.

Keywords*:* Low power, Accuracy, Precision, Modeling.

I. INTRODUCTION

Minimizing power consumption of embedded systems is a crucial task. Battery-operated portable systems demand tight constraints on energy consumption. Better low-power circuit design techniques and advances in battery technology have helped to increase battery lifetime. On the other hand, managing power dissipation at higher design levels can considerably reduce energy consumption, and thus increase battery lifetime [1]. Moreover, the current tendency towards the applications integrating a multitude of functionalities generally supports multiprocessors architectures having high performances. To guarantee the feasibility of these systems, it is thus necessary to prospect new software and material architectural solutions guaranteeing a high performance and low consumption. At the same time, one of the major problems in low power design is the evaluation of the energy dissipated by architecture.

Indeed, current researches [1][2][3] are based on measures or on estimation in order to evaluate consumption. The results of such methods are generally with some errors due to the precision and the accuracy of the measurement device or due to the estimation tool. This problem is more predominant in architectures having an important number of software and/or hardware resources, due to the accumulation of errors. Hence the necessity of an energetic modelling methodology which allows to guarantee a confidence interval for global estimates. This is the problem that we address.

To achieve this objective, some researchers [4][5] have improved various techniques and tools to minimize the error in consumption estimate on a processor or a given FPGA. However a minority of works deal with the accuracy and the precision problem of the estimates for rather complex architectures.[6]

In this article, we present a consumption estimate methodology of complex systems with indication of the accuracy and the global precision. This methodology rests on approaches of probability and statistics making it possible to validate the estimates accuracy. In section II we present a state of the art. In the third section we show the mathematical approach. In section IV we present the utility of this approach in low power design.

II. RELATED WORK

The emergences of mobile application have introduced several new challenges in energy management. The mobility of device such as MP3 players, laptop, PDA and cellular phones implies that they are powered by mobile power sources which are limited. So, the need to manage energy consumption becomes crucial. Many solutions have been presented at various levels of abstraction especially in the high level which is the most attractive.

In order to reach these low power solutions, the energy and time estimation or measurements are useful. Indeed, the latter allows modelling the system consumption according to the application and architecture parameters. This makes the solutions space exploration rather large and realistic, and permits to validate the solution. Generally, the consumption estimate tools are not very precise or they are precise for only simples cases of evaluation on a given abstraction level (Asm, C, System-C, VHDL-RTL, etc)[7][8]. However, since the architectures have become enormously complex with the emergence of the multiprocessors, the estimate tools are unable to consider the global consumption of the target with precision.

In fact, due to the presence of the software (System-C, C, Asm, etc) and of the hardware in the same architecture [9], the precise consumption estimation with a tool is rather complex. In addition, the recourse to real consumption measurements on board is rather costly in terms of time to market and cost. Indeed, this requires a specific test platform and adequate measuring instruments.[10] Moreover, any modification of software/hardware partitioning involves the modification of the measurement platform. Hence the need for a new estimate methodology with details about accuracy. This methodology is based on mathematical approaches.

The next section treats the mathematical approach of elaborating power and performances accuracy models.

III. PROBABILISTICS ANALYSIS

When we discuss measurements or the results of measuring instruments, there are several distinct concepts involved which are often confused with one another like the distinction between accuracy, uncertainty and precision. In fact, accuracy refers to the agreement between a measurement and the true or correct value. The accuracy cannot be discussed meaningfully unless the true value is known or is knowable. But precision refers to the repeatability of measurement. It does not require the knowledge of the correct or the true value.(Figure 1)

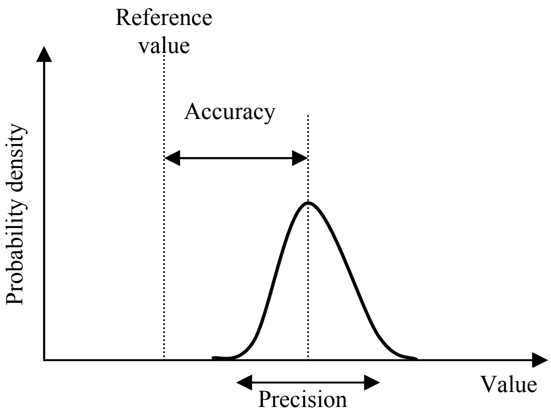

Figure 1. Difference between precision and accuracy on measures

Whereas, uncertainty of a measured value permits to define an interval around that value so that any repetition of the measurement will produce a new result that lies within this interval. Furthermore, when estimating, it is important that our estimation be as accurate as possible. However, no matter how well we can make the estimate, there is always some uncertainty which is introduced. Indeed, there are two independent sources of this uncertainty. The first arises from the estimating process itself, while the second is due to the precision of the measuring device. Mathematically, when several measurements of a normal distributions quantity are taken, the uncertainty can be estimated by computing an average deviation. (Figure 2)

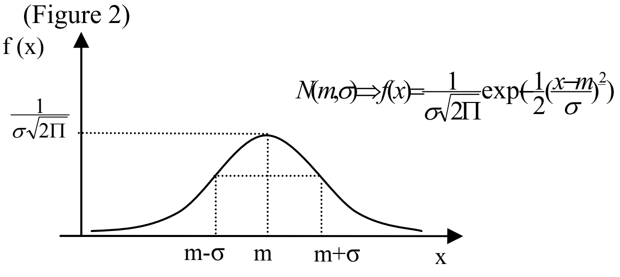

Figure 2. Normal distribution of measures

It is sometimes possible to identify an interval so that we can assert that this interval "covers" the true value of the measure with a certain given probability *P*. This interval is then called a confidence interval for the estimate value. The width of the confidence interval is a measure of the uncertainty about the position of the true value of the estimated parameter.

The probability *P* is arbitrarily chosen by the designer. It is called the confidence level for the confidence interval, and is denoted by $(1 - \alpha)$. The most frequently chosen values for α are 0.05 and 0.01, corresponding to 95% and 99% confidence levels.

In most practical research, the standard deviation (σ) for the population such as the energy consumed or power is not known. In this case, the standard deviation is replaced by the estimated standard deviation (s). Since the standard error is an estimate for the true value of the standard deviation, the distribution of the sample mean X is no longer normal with mean (μ) and standard deviation ($\sigma/n^{0.5}$). Instead, the sample mean (μ) follows the *t* distribution with mean and standard deviation ($s/n^{0.5}$). The (t) distribution is also described by its degrees of freedom. For a sample of size n, the (t) distribution will have n-1 degrees of freedom. As the sample size n increases, the (t) distribution becomes closer to the normal distribution, since the standard error approaches the true standard deviation (σ) for large n.

Moreover, if we have two independent populations X and Y with normal distributions $N(m1,\sigma1^2)$ and $N(m2,\sigma2^2)$ respectively, their sum is also a normal distribution $N(m1+m2, \sigma1^2+\sigma2^2)$. This rule permits for example to estimate the mean and the deviation of the global consumption of two or more DSPs running together.

In this work, we use the confidence interval to express the precision and uncertainty of current or time models for example, associated with an estimation framework. In the computing of the confidence interval, three elements are involved. The first is the sample size, the second is the reliability of the result represented by the confidence coefficient and the third is the result precision represented by the width of the confidence interval.

IV. STATISTICS IN LOW POWER DESIGN

The proposed method consists in a high-level of consumption and accuracy estimation technique. The energy consumption models are extracted in the beginning thanks to measures on many DSPs and to tools such as Soft Explorer and Code Composer. The proposed estimation approach exploits parametric models representing the consumption’s behaviour of both DSP’s architecture and algorithm. This consists in releasing the laws of consumption on a high level. This approach is based on a functional level power analysis. Its advantage is that the consumption and the performance estimations can be made at a high level. This methodology starts from the extraction of the algorithmic, architectural and technological parameters which have a direct influence on the consumption of the application (image size, resolution, number of images per second, computing precision, target, frequency). The following stage consists in extracting the consumption variation according to each parameter extracted through estimates or measurements thanks to scenarios. Finally, the mathematical formulation of consumption laws according to these parameters. (Figure 3)[11]

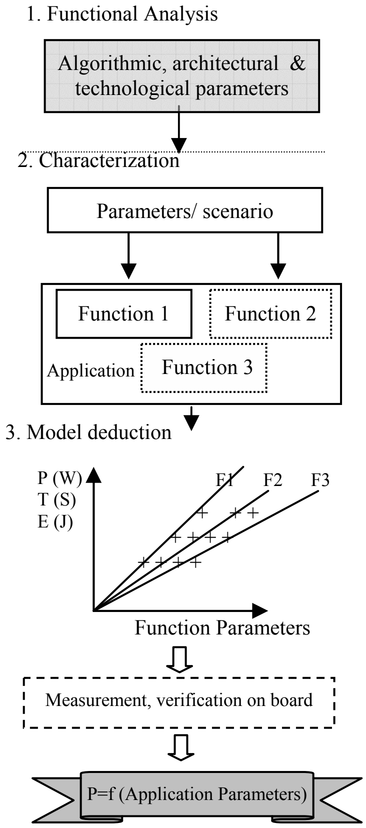

Figure 3. Transposed FLPA for IP(SW)

A confrontation of the models established with measurements on mono-DSP board is possible in order to have an idea about the accuracy of these models according to the application parameters.

Nowadays, the mainly used architectures are the multiprocessor target and ASICs. In such situations, the main problem in low power design concerns the consumption estimation of the whole architecture and the attainment of the confidence interval, which is based on the consumption model for each DSP. This is the problem that we address. In fact, for most of applications, a large number of Hw/Sw solutions can be explored and evaluated without need to any board due to the cost measures and due to time to market. For this reason, the probabilistic approach is necessary in order to consider total consumption with precision.

Let us take an application (four tasks) written in C. The virtual target architecture can contain up to three DSPs. For some tasks, the consumption modeling is made by six measurements on each mono-DSP board. For the other tasks (ANSI-C), it is made with SoftExplorer estimate tool whose error is ±7% with confidence of 95%. Thus, there will be 12 models of consumption ($P_{Task(i), Target(j)}$). (Figure 4)

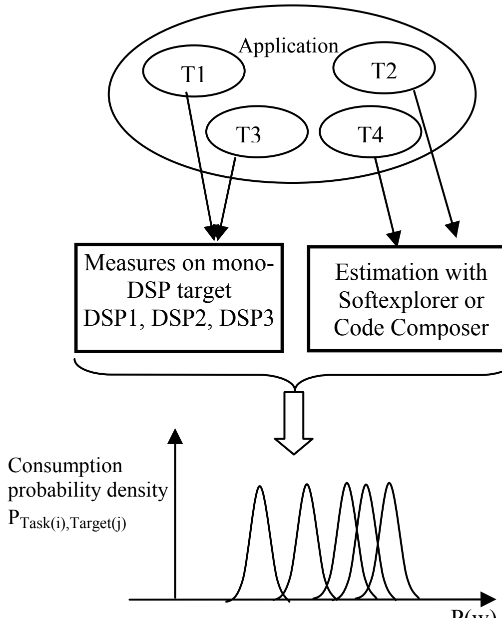

Figure 4. Probabilistic consumption approach

From the consumption and time probability density for each task running on each DSP, It is important to extract the global performance and consumption. For this reason the consumption probability density will be calculated using the formula (1 and 2).

For example, f_t is the execution time probability density of $task_i$ and f_p is the power probability density extracted using measures or estimation, so f_e which is the energy probability density will be equal to:

$$f_e(e) = \int_{-\infty}^{+\infty} \frac{1}{|u|} f_t(u) * f_p\left(\frac{e}{u}\right) du \qquad (1)$$

$$f_e(e) = \frac{1}{2\Pi\, \sigma_t \sigma_p} \int_{-\infty}^{+\infty} \frac{1}{|u|} \exp^{1/2\left[\left(\frac{u-m_t}{\sigma_t}\right)^2 + \left(\frac{\frac{e}{u}-m_p}{\sigma_p}\right)^2\right]} du \qquad (2)$$

The figure 5 shows as an example the time, power and the calculated energy probability density of the $task_i$ running on DSP_j.

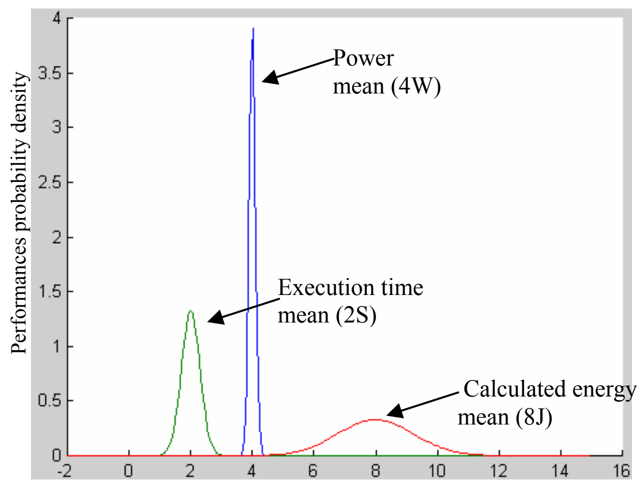

Figure 5. Time, power and the calculated energy probability density

We can conclude that the energy probability density is also a normal distribution with mean (μ_e) and standard deviation (σ_e). Thanks to this approach, we can estimate the mean and the standard deviation of the whole application consumption. This permits also to compute the expected accuracy of estimations.

Concerning the confidence interval: for a population with unknown mean μ and unknown standard deviation, the confidence interval for a chosen confidence level (1 - α) and for a population based on a n random sample, is :

$$\overline{X} - t_\alpha \frac{\hat{\sigma}}{\sqrt{n}} \leq \mu \leq \overline{X} + t_\alpha \frac{\hat{\sigma}}{\sqrt{n}} \quad (3)$$

Where t_α is the t *"student distribution"* with *n-1* degrees of freedom.

V. EXPERIMENTS

We show in table 1 the consumption confidence interval of the most important MPEG2 tasks running on a chosen DSP(C5510, C6201 and C6701). These intervals are based on measures or estimation. The error estimation with SoftExplorer is ±7% with confidence level (95%)[3]. While, for estimations with (six) measures on board, we compute the mean and the deviation for each task:

$$\overline{X} = \frac{1}{\mathrm{n}} \sum_{i=1}^{6} (measures(i)) \qquad (4)$$

$$\hat{\sigma} = \sqrt{\frac{1}{\mathrm{n\text{-}1}} \sum_{i=1}^{6} (measures(i) - \overline{X})^2} \qquad (5)$$

Based on the consumption confidence interval of each task and through the proposed mathematical approach, we are able to compute the accuracy of the whole multiprocessor application and the confidence interval for a chosen confidence level (90%). (Table1)

Table 1. Accuracy of the energetic confidence interval

Tasks / DSPs	Estimation method	Confidence interval (Joule)	Confidence level	Estimated $\overline{X}$ and σ
Motion estimation / C5510	SoftExplorer	4J±7% [4-0.28 4+0.28]	95%	$\overline{X}$ =4 σ =0.27
Prediction / C5510	SoftExplorer	2J±7% [2-0.14 2+0.14]	95%	$\overline{X}$ =2 σ =0.13
DCT/ C6201	6 Measures	[2.3-0.12 2.3+0.12] 2.3J±5.6%	95%	$\overline{X}$ =2.30 σ=0.128
Quantif/ C67	6 Measures	[4.27-0.16 4.27+0.16] 4.27J±3.8%	95%	$\overline{X}$ =4.27 σ=0.164
Application: MPEG2				
Probabilistic estimation		[12.57-0.297 12.57+0.297] 12.57J±2.3%	90%	$\overline{X}$ =12.57 σ=0.712^0.5

The global consumption of this application is about 12.57J±2.3% with a confidence level of 90%. Figure 6 shows the normal distribution of the energy consumed by the target composed of three DSP. We have only 90 chances in 100 that the required MPEG2 energy value is within the confidence interval, but the precision around the predicted value is so high (±2.3%).(Figure 6)

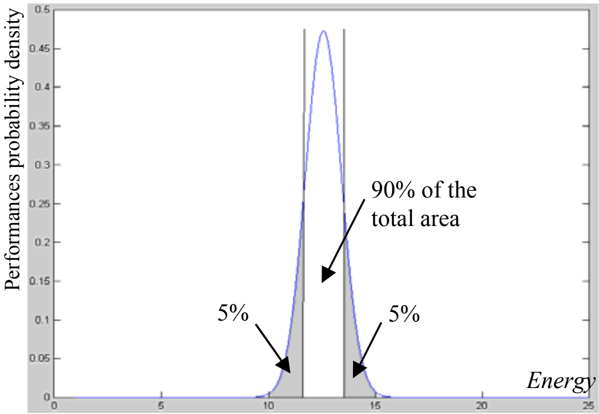

Figure 6. Graphical accuracy and precision of the methodology

VI. CONCLUSION

In this paper, we have proposed a novel methodology for dealing with accuracy and precision in high level consumption estimation. The approach, which resides in a design exploration methodology, is based on tools and measures on boards. Mathematical approach provides a probabilistic estimation computing to retrieve the confidence interval. This methodology offers the designer an opportunity to model the application consumption in a high level for different target. It permits also to extract the energetic performance of the whole architecture without a need to a multiprocessor board. This will help the designer in choosing the adequate application implementation, and in giving a good idea about the constraints for further development.

We expect to apply this mathematical approach on an H264 example in the near future.

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