

## Chapter 18

# Duty Cycle Measurement Techniques for Adaptive and Resilient Autonomic Systems

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### ABSTRACT

*When systems are deployed in environments where change is the rule rather than the exception, adaptability and resilience play a crucial role in order to preserve good quality of service. This work analyses methods that can be adopted for the duty cycle measurement of sensor-originated waveforms. These methods start from the assumption that no regular sampling is possible and thus they are naturally thought for an adaptive coexistence with other heterogeneous and variable tasks. Hence, the waveform carrying the information from low-priority sensors can be sampled only at instants that are non-controlled. To tackle this problem, this paper proposes some algorithms for the duty cycle measurement of a digital pulse train signal that is sampled at random instants. The solutions are easy to implement and lightweight so that they can be scheduled in extremely loaded microcontrollers. The results show a fast convergence to the duty cycle value; in particular, a considerable gain with respect to other known solutions is obtained in terms of the average number of samples necessary to evaluate the duty cycle with a desired accuracy is obtained.*

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## 1. INTRODUCTION

One of the options for the deployment of systems able to sense and react to environment changes exploiting some redundancy to possibly provide robust and dependable behaviors is the creation of a network of simple nodes with both sensing, processing and communication abilities. In such a framework, the limited energy budget of every node (Rao, Vrudhula, & Rakhmatov, 2003; Moragrega, Ibars, & Geng, 2009) often implies large sleeping times with asynchronous wake-ups (Vigorito, Ganesan, & Barto, 2007) stimulated by high priority tasks due to communication or coordination.

To be environment-aware, wake-ups must be also used to monitor available sensors whose readings can be collected in those short time-slices of the microcontroller that are left idle from higher-priority tasks.

This configuration may easily cope with sensors whose reading is immediately available at a digital or analog port. Yet the deployment of such sensors can be over killing when extremely slowly varying physical quantities have to be monitored and/or when the number of wires that can be employed for the connection between the sensing and processing units must be kept to a minimum. For example, sensors exist that communicate their output by modulating a square wave so that its duty cycle is proportional to the measured physical quantity. TMP03 (<http://www.analog.com>) and SMT160-30 (<http://www.smartec.nl/pdf/DSSMT16030.PDF>) are among these and may be used to sense temperature in sensor networks for environmental monitoring (Lach, Evans, McCune, & Brandon, 2003; Lan, Qilong, & Du, 2008).

The most common method for duty cycle measurements is to read high and low periods by means of a timer/counter port (de Jong & Toth, n.d.) of the microcontroller. An alternative idea is introduced in (Bhatti, Denneau, & Draper, 2005) and is based on random sampling and on the ap-

plication of the Law of Large Numbers (Spiegel, 1975): the state of the square wave is repeatedly sampled at the edges of a random clock; if the duty cycle of the signal is  $D$ , then the probability of sampling a high signal level in each trial is equal to  $D$ ; the duty cycle is then calculated as the ratio between the number  $H$  of the high samples and the total number of samples  $N$ ; since we have  $\lim_{n \rightarrow \infty} \frac{H}{N} = D$ ; the accuracy increases arbitrarily as the number of samples increases. In the rest of the paper we refer to this algorithm with the term Count Active Algorithm, CAA.

The random sampling technique is particularly interesting for our scenario. In fact, since both the wake-ups and the idle time-slices within the working intervals cannot be predicted at design-time, information about the signal status can be inherently collected only in a random set of time-instants. Note that, in this sense, the random occurrence of the samples is something that our approach has to cope with and not some working hypothesis that we impose to the system: the random behavior of the sampling activity is naturally dictated by the operating system that collects the samples only during its idle periods of time.

In Taddia and Mazzini (2006) we have proposed three novel algorithms based on a random sampling approach to calculate the duty cycle of a square wave. We suppose to know the signal period and the temporal instants in correspondence of the signal rising edges; furthermore we suppose to work with a signal that maintains a constant period. All these are solutions that can be easily implemented on microcontrollers. In Taddia and Mazzini (2006) we have presented simulation results that show a considerable gain in terms of number of samples necessary to obtain a desired error level: our solutions can estimate the duty cycle with an average error of  $10^{-2}$  after  $N = 50$  samples, while the (Bhatti, Denneau, & Draper, 2005) would require  $N = 1000$  samples. In our previous works (Taddia & Mazzini, 2006; Taddia, Mazzini, & Rovatti, 2010) we have calculated

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