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Constraints definition and application optimization based on geometric analysis of the frequency measurement method by pulse coincidence

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ABSTRACT

In this paper a new and more efficient algorithm for frequency measurement using pulse coincidence is introduced. This novel approach reduces 42% the measurement time while the same accuracy is maintained. The simplicity of the algorithm proposed in this work is compared with other similar methods that are related with analog to digital converters and the discrete Fourier transform. Geometric analysis was performed to the signals involved in the frequency measurement process in order to obtain mathematical parameters for the correct implementation of this new method. Simulated signals and generated signals from a homemade system were used to validate this method's scope.

1. Introduction

The problem of adequate frequency estimation during the reasonable time is traditionally of paramount importance in many branches of electronic industry. Due to its high relevance in versatile practical applications, many research groups dedicate their papers to this topic. Vizireanu introduced an algorithm for instantaneous frequency estimation based on four equally spaced samples and an analog to digital converter (ADC) with accurate results [1]; although, this method is sensitive to variation in the sample rate, depends on dedicated architectures for efficiency, and also the samples must be taken faster than a quarter of the signal. Unlike the method presented in this paper, which is asynchronous and the algorithm needed its simple enough to be handled by a low profile microcontroller. A simple frequency estimation method is also presented by Vizireanu in [2], but even if it uses just three samples of a signal and the method is fast, its implementation is focused on the standards of electric power systems, leaving behind a wide range of frequencies and applications.

Mostarac, Malaric and Hegedus introduced a new algorithm for instantaneous frequency measurement achieving satisfactory results performing two tasks; one of them measure the signal by continuously monitoring it, and the second task evaluates the information [3]. Despite the results obtained, this method relies in ADC and a heavier information process than the one presented in this paper.

In the past decades the discrete Fourier transform (DFT) was used to estimate the frequency of a signal in a variety of papers such as [4–11]. While they were focusing in the signal noise ratio (SNR), each new paper introduced a new improvement: some of them contribute in terms of the accuracy, the algorithm's complexity, or the number of samples needed. In 2016 Jinzhi, Qing and Wei used as starting point some of the previous mentioned papers to introduce in [12] an algorithm of interpolation in order to improve performance; although, the results presented are in terms of probability. The present paper offers a geometric and numerical analysis, the complexity of the algorithm in [12] is bigger than the one in this paper. The main objective of the present work is the optimization of the mediant fractions approximation method based on systematized analysis of all possible geometric constraints, which can limit or decrease its potential efficiency.

2. Problem definition

This paper describes the method of frequency measurement by pulse

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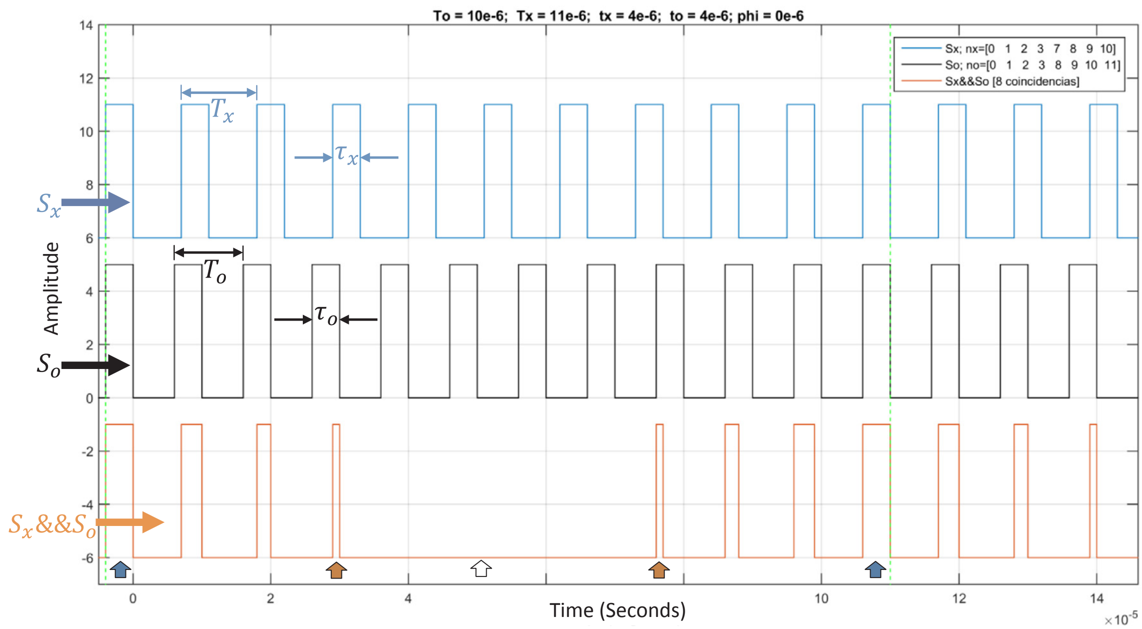

Fig. 1. Graphic representation of the pulse coincidence method.

coincidence. Based on simulations, the effect of the pulse width of the signals involved in the measurement process is described. Later, the way in which the pulse coincidence method is related to Euclid's algorithm is described. Partially, some aspects of the theory of frequency measurement based on the coincidences of pulses of two independent trains were introduced in our previous publications [13–16]. However in [13–16] never was observed the detailed geometric analysis, neither specific natural constraints of method availability. The present work is based on versatile simulations to identify the specific conditions and constraints of our method applicability. Finally, and based on the analysis above, a new criterion to finish the measurement is introduced as well as its limitations. For this paper consider:

- A known signal S_o, with period To, pulse width τo and frequency f_o (see Fig. 1).
- T_o as an integer of To; ergo, To $= T_o \times 10^{-r}$ s. ($r = 3$ for milliseconds, $r = 6$ for microseconds, and so on).
- τ_o (not necessarily an integer) will have the same ratio with τo, as T_o has with To; ergo, τo $= \tau_o \times 10^r$ s.
- A theoretically unknown signal S_x, with period Tx, pulse width τx and frequency f_x.
- T_x as an integer of Tx; ergo, Tx $= T_x \times 10^{-r}$ s.
- τ_x (not necessarily an integer) will have the same ratio with τx, as T_x has with Tx; ergo, τx $= \tau_x \times 10^r$ s.
- τ will involve both τ_o and τ_x; in this case, consider $\tau_o = \tau_x$.
- *GCD* as the greatest common divisor of T_o and T_x.
- $\frac{\tau}{GCD}$ as the least integer greater than or equal to $\frac{\tau}{GCD}$.
- φ as the initial phase (reference coincidence) between S_o and S_x (see Fig. 2).

As mentioned in [13], the method of frequency measurement by pulse coincidence consists of counting the number of complete periods of two signals, using as reference a moment in which simultaneously the positive semi-cycles of both signals are present (coincidence), and save the count for each signal in every coincidence. S_o will be a reference signal, and its respective period T_o will be used to find the period T_x and the frequency f_x of the signal S_x. In this method, the relationship between the periods of the signals S_o and S_x is given by:

$$N_o(i)T_o = N_x(i)T_x, \tag{1}$$

where $N_o(i)$ and $N_x(i)$ are the number of complete periods for an i-th coincidence of T_o and T_x respectively. A condition given in [14, p. 91] to finish the measurement process, is when $N_x(m)$ has the form $T_o \times 10^s$; when this happen, $N_o(m)$ will have the form $T_x \times 10^s$, and Eq. (1) is rewritten as:

$$T_x = \frac{N_o(m)T_o}{N_x(m)} = \frac{(T_x \times 10^s)T_o}{T_o \times 10^s}. \tag{2}$$

As an example, Fig. 1 shows a simulation of two signals S_x and S_o (in blue and black, respectively), and a third signal in red ($S_X\,\&\,\&S_o$) corresponding to the coincidences given by the signals S_x and S_o. Consider the first pulse of $S_X\,\&\,\&S_o$ as reference coincidence, the condition to finish the measurement is reached in the red pulse in 11×10^{-5} s. In this simulation, the first falling edge of S_x and S_o are aligned.

It is important to realize from (2) and the example in Fig. 1, that $N_x(m)$ is a dimensionless value and $r \neq s$; in Fig. 1, $r = 6$ (from $T_o = 10$ and To $= T_o \times 10^{-6}$*sec.*), $s = 0$ (from the 8th coincidence, $N_x(8) = T_o \times 10^0$). The previous explanation means that r must be taken from the reference (known) signal, along with T_x from (2) in order to calculate the period Tx $= T_x \times 10^{-r}$ s. associated with S_X.

After simulations performed with a difference of time $\varphi > 0$ seconds between the first falling edge of S_x and the first falling edge of S_o, for example in Fig. 2, with $\varphi = 2 \times 10^{-6}$ s. Analysis of simulations shows that displacement of S_x to the right causes that pulses of coincidences are displaced to the left as long as $T_x > T_o$.

From this first analysis, we can conclude that a modification of φ can be useful if we need to displace the coincidence pulses.

3. Effect of pulse widths in signals s_x and s_o

In a measurement, two types of coincidences can exist; those where the pulses of the signals S_x and S_o are fully aligned/overlapped (ideal coincidence), and those where pulses of the signals S_x and S_o are partially aligned/overlapped (partial coincidence). In Figs. 1 and 2, ideal coincidences are indicated with ⬆, the remaining coincidences are partial.

In the measurement by pulse coincidence method, it has been found that τ is associated with the number of coincidences given in a measurement. There's a minimum value for τ; from which partial coincidences will appear in a measurement. On other hand, the presence