Control loop performance assessment using running discrete Fourier transform

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1 Introduction

Control loop performance assessment (CLPA) techniques are crucial for optimizing any plant or machine. They can bring huge energy and material savings and increase product quality. Although the positive CLPA impact is evident, the utilization of CLPA is still undervalued. The controllers are tuned only once, they often work with default parameters or in manual mode. Even when the controllers are initially tuned they must be continuously monitored because the process dynamics may change and the sensors and actuators can degrade over certain time period. Hence, it is not surprising that renowned studies estimate that about 70% of control loops are not properly tuned (Ender (1993)).

In many technical branches, *Fast Fourier Transform* (FFT) is used to compute discrete Fourier transform and to get the frequency characteristic of a signal (Lo (1999)). When only a signal power at selected frequencies is needed, the *Running Discrete Fourier Transform* (RDFT) is more effective. In this paper, development of new RDFT function block which is suitable for CLPA is described. Then one of many possible applications in CLPA field is introduced.

2 RDFT and its applications in CLPA

Discrete Fourier transform (DFT) is very useful and widely used tool for analyzing periodic signals. Recursive formulas for computing real and imaginary parts of Fourier transform on single frequency are:

$$\begin{aligned} \mathrm{Re}(U_{n+1}) &= A\left[\mathrm{Re}(U_n) - u_n + Cu_{n+M}\right] - B\left[\mathrm{Im}(U_n) + Du_{n+M}\right], \\ \mathrm{Im}(U_{n+1}) &= A\left[\mathrm{Im}(U_n) + Du_{n+M}\right] - B\left[\mathrm{Re}(U_n) - u_n + Cu_{n+M}\right], \end{aligned} \tag{1}$$

where $A = \cos \omega T$, $B = \sin \omega T$, $C = \cos(-M\omega T)$, $D = \sin(-M\omega T)$ and T is the sampling period. The energy $E^2(U_n)$ of the signal $u(n)$ on chosen frequency ω is

$$E^2(U_n) = \mathrm{Re}^2(U_n) + \mathrm{Im}^2(U_n). \tag{2}$$

The new RDFT block is based on two separate cyclic buffers which allow optimizing computational burden and attenuate numerical errors which are cumulated in many algorithms when running over longer time period. The algorithm described by equations (1,2) was implemented in a function block called RDFT which was extensively tested. This block became a part of the RexLib library (Balda (2005)).

There are many possible applications of RDFT block in CLPA field. One of these methods, where is RDFT used for the estimation of control loop performance index will, be briefly presented. More specifically, key samples of sensitivity function are gained and compared to

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the reference ones. Inspired by the model free design techniques, only a minimum *a priori* information about the process is assumed. The only assumptions are that the process $P(s)$ is essentially monotone and the controller $C(s)$ contains an integrator. The big advantage is that it is parameterized by only two numbers Ω_a (available bandwidth) and M_S (maximum of sensitivity function) which in fact define the reference loop performance. After applying Bode's theorem one gets

$$\int_0^{\Omega_a} \ln(|S(\mathrm{j}\omega)|)\,\mathrm{d}\,\omega = \int_0^{\Omega_1} \ln\left(\frac{M_S}{\Omega_1}\omega\right)\mathrm{d}\,\omega + (\Omega_a - \Omega_1)\ln M_S \doteq 0, \tag{3}$$

consequently $\Omega_1 \doteq \Omega_a \ln M_S$ and $\Omega_0 \doteq \Omega_a \ln M_S / M_S$. Naturally, the output disturbance d_o (see Fig. 1) is present in every control loop. One can select a frequency ω_d with sufficiently high energy in the interval $(0,\ \Omega_0)$. Using RDFT the spectrum amplitude of this frequency is determined for both closed (A_y) and open (A_d) feedback. Ratio of those amplitudes defines the actual value of sensitivity function $S(\mathrm{j}\omega_d)| = \frac{A_y}{A_d}$. Then the performance index enumerates the distance between ideal and actual sensitivity function. Final relation for performance index is

$$I_p \doteq \frac{\frac{\Omega_a}{\omega_d}(1 - \frac{A_y}{A_d})\ln M_S}{\frac{\Omega_a}{\omega_d}1 - M_s} = \frac{1 - \frac{A_y}{A_d}}{1 - \frac{\omega_d}{\Omega_a}\frac{M_s}{\ln M_s}}. \tag{4}$$

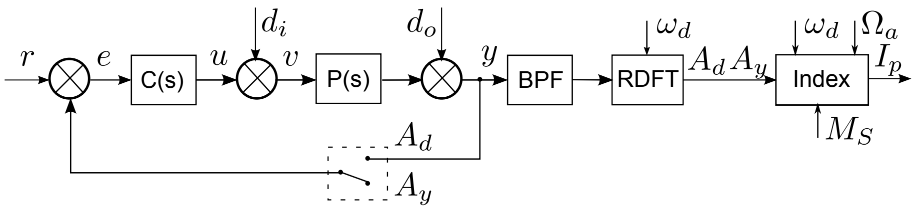

Figure 1: Function scheme of system evaluating control loop performance by estimating actual value of sensitivity function on frequency . ω_d

3 Conclusion

The new running discrete Fourier transform (RDFT) function block was introduced. It was shown that using two separate buffers decrease the amount of arithmetic errors. Then one perspective application of (RDFT) – estimation of control loop performance index was presented. In the future, there will be put effort to transfer presented ideas into industrial practice.

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