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DYNAMIC SYSTEM IDENTIFIER "DPI-3": EXPERIMENTAL INVESTIGATIONS

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ABSTRACT
Results of experimental investigations of the dynamic system identifier DPI-3 are given. DPI-3 is a C program for the single-board computer. In contrast to DPI-2D, a total identification time is significantly reduced in DPI-3. It is achieved by using of new identification algorithms. A physical plant model (PPM), which is electrical device, was used in the experimental investigations. The PPM contains a source of the external disturbance. Realized experimental investigations show a high accuracy of identification and also reducing of total time more than in twice.

KEY WORDS
Frequency identification, parametric identification, software, experimental investigation

1. Introduction

At present, the control theory has at its disposal a number of identification methods for plants specified by linear differential equations. Conventionally, these methods fall into two categories depending on the assumptions on the measurement errors and exogenous disturbances affecting the plant.

The methods of the first class deal with the plants subjected to disturbances of the stochastic nature; i.e., random processes having known statistical characteristics. These are various versions of the method of least squares and the stochastic approximation method; e.g., see well-known monograph [1].

The second class comprises the identification methods under unknown-but-bounded disturbances (whose statistical properties are not known) such as randomized algorithms of [2] and finite-frequency identification, see [3].

The identification process can have passive or active forms. In the passive identification, the measured input to the plant has the meaning of a control action which depends on the control objectives and is not related to identification of the plant. With such an input, identification might not be possible; hence, active identification is often practiced where, in addition to control, the measured input contains an extra component, a so-called test signal aimed at identifying the plant.

The finite-frequency identification method was designed for the needs of active identification. The test signal is represented by the sum of harmonics with automatically tuned (self-tuned) amplitudes and frequencies [4] where the number of harmonics does not exceed the state space dimension of the plant.

DPI-3 is a C++ program for single-board Via Athena ATH-660-128 computer. It means for identification of the linear dynamic systems. An algorithm of this program is based on a new finite-frequency identification method.

A first identifier DPI-1 [5] was designed to get more precise parameters for an approximately known plant. This is assembler program which was realized on ADSP-21990 mixed-signal controller.

A second identifier DPI-2D was designed [6]. In this case plant order, sampling interval and bounds of signal are known. This is C++ program for personal computer with ADC-DAC board named L-780. It allows identify wide class of control plant with different physical nature.

In papers a result of experimental investigations of identifies using DPI-3 program is given. DPI-3 essentially is upgraded DPI-2D identifier. As compared with DPI-2D, thanks to more modern hardware and the perfected algorithm, the results give increase of precision.

2. Applications

2.1 Purpose

A continuous-time plant is described by the following differential equation:

$$y^{(n)}(t) + d_{n-1}y^{(n-1)}(t) + \ldots + d_1 y'(t) + d_0 y(t) =$$
$$= k_m u^{(m)}(t) + \ldots + k_0 u(t) + f(t),\ m < n, \quad (1)$$

where $y(t)$ is the output of the plant, $u(t)$ is a controllable input, $f(t)$ is an unknown-but-bounded disturbance:

$$|f(t)| \le f^*, \quad (2)$$

where f^* is given power of external disturbance, coefficients d_i $(i = \overline{0, n-1})$ and k_i $(i = \overline{0, m})$ are unknown numbers, n is the known order of plant.

Input and output are bounded:

$$|u(t)| \le u\_, \ |y(t)| \le y\_ , \tag{3}$$

where $u\_$ and $y\_$ are known input and output range limits.

The purpose is to estimate the coefficients d_i $(i = \overline{0, n-1})$ and k_i $(i = \overline{0, m})$.

2.2 Source data

The sources for DPI-3 are:

- the plant order n;
- the bounds of signals (see(3));
- a frequency band M,
- a power of external disturbance f^* (see (2)).

3. Program structure and algorithm

An identification algorithm DPI-3 is based on a finite-frequency identification method with self-tuning of test signal amplitudes and durations without any interrupts of the test signal. A block diagram of DPI-3 appears on figure 1.

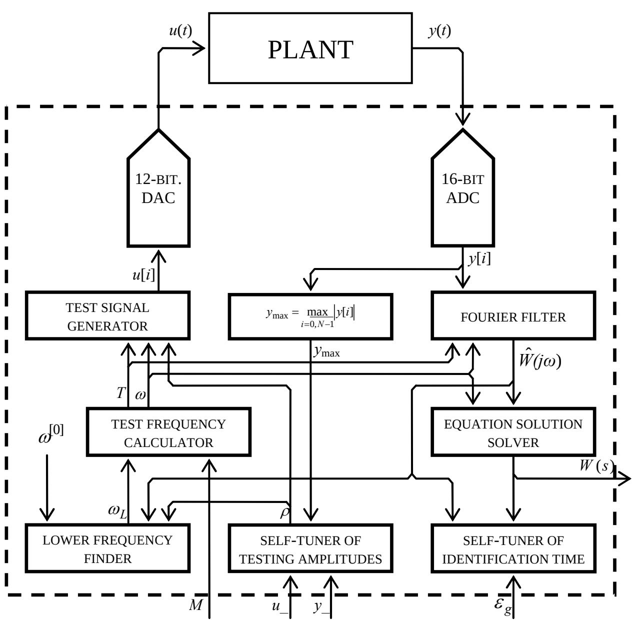

Figure 1. DPI-3 block diagram

3.1 Test signal generator

A test signal generator forms the polyharmonical signal:

$$u[ih] = \sum_{k=1}^{n} \rho_k \sin \omega_k ih, \quad i = \overline{0, N-1}, \ k = \overline{1, n} , \tag{4}$$

where $\rho = [\rho_1, \ldots, \rho_n]$ is a testing amplitude vector, $\omega = [\omega_1, \ldots, \omega_n]$ is a testing frequency vector, N is a number of a sampling intervals which equals 4096 samples for ever period; h is a sampling interval:

$$h = T / N ,$$

where T is a period of the basic frequency ω_1, which is determined as:

$$T = \frac{2\pi}{\omega_1} .$$

The definitions for ρ and ω are described later on.

3.2 Fourier filter

A Fourier filter evaluates frequency parameters of the plant (1) approximately:

$$\begin{aligned} \hat{\alpha}_k(\gamma) &= \frac{2}{\rho_k \gamma N} \sum_{i=0}^{\gamma N-1} y[ih] \sin \omega_k ih \\ \hat{\beta}_k(\gamma) &= \frac{2}{\rho_k \gamma N} \sum_{i=0}^{\gamma N-1} y[ih] \cos \omega_k ih \end{aligned} \quad k = \overline{1, n} , \tag{5}$$

where γ is a number of the base period.

3.3 Frequency equations solver

A solver estimates plant coefficients (1), using plant frequency parameters (5) on the input. A continuous-time transfer function is:

$$W(s) = \frac{k_m s^m + \ldots + k_0}{s^n + d_{n-1} s^{n-1} + \ldots + d_0} = \frac{k(s)}{d(s)} , \tag{6}$$

where s is a Laplace transformation operator.

The frequency parameters (5) of plant (1) relates to its transfer function (6) so:

$$W(j\omega_k) = \frac{k(j\omega_k)}{d(j\omega_k)} = \alpha_k + j\beta_k , \quad k = \overline{1, n} .$$

When the solver substitutes estimates (5) instead of α and β, it gets frequency equations, which solving is necessary for estimating the polynomials $\hat{k}(s)$ and $\hat{d}(s)$ of the transfer function (6):

$$\hat{k}(j\omega) - (\hat{\alpha}_k + j\hat{\beta}_k)\hat{d}(j\omega) = 0, \quad k = \overline{1, n} . \tag{7}$$

3.4 Self-tuning of testing amplitudes

This part is necessary for determine of the amplitude ρ. The plant (1) is being tested by signal:

$$u[ih] = a\sum_{k=1}^{n}\rho_k \sin\omega_k ih, \quad i = \overline{0, N-1},$$

where vector ρ are calculated as:

$$\rho_j = 0{,}9\frac{u\_\omega_j}{\sum_{k=1}^{n}\omega_k}, \ \ j = \overline{1,n},$$

and a, at first, is

$a = 1$.

Then verifying of the condition to the plant output occurs:

$$|y[ih]| \le 0{,}95 y\_, \quad i = \overline{0, N-1}. \tag{8}$$

If this condition doesn't hold, the number a should be decreased, and the experiment repeats until condition (8) is satisfied.

3.5 Plant testing with self-tuning of identification time

Instead of test duration self-tuning method described in paper [7], the following method is applied.

There is a background cycle that is controlled by a main program. The background cycle applies the test signal to the plant and reads the plant output. The main program performs all other computations independently of the background cycle.

After the testing signal (4) is determined, a testing of the plant begins. The main program enables a background cycle and waits for an end of the second duration (data is ignored during the first duration because it is a delay for transient). Immediately after these durations, estimations of the frequency parameters for $\gamma = 1$ are produced:

$$\begin{aligned}\hat\alpha_k^{[\gamma]}(\gamma N) &= \frac{2}{\rho_k \gamma N}\sum_{i=0}^{\gamma N-1} y[ih]\sin\omega_k ih \\ \hat\beta_k^{[\gamma]}(\gamma N) &= \frac{2}{\rho_k \gamma N}\sum_{i=0}^{\gamma N-1} y[ih]\cos\omega_k ih\end{aligned} \quad k = \overline{1,n}.$$

Frequency equations (7) are solved to get the coefficients of the plant transfer function are getting (1):

$$\hat W^{[\gamma]}(s) = \frac{k_m^{[\gamma]}s^m + \ldots + k_0^{[\gamma]}}{s^n + d_{n-1}^{[\gamma]}s^{n-1} + \ldots + d_0^{[\gamma]}}.$$

After this, the test should be repeated (without any delays), and parameters (9) and (10) are obtained for $\gamma = 2$. Then maximum of relative accuracies in determining of frequency parameters and coefficients of transfer function between current and last periods is given by the formulae:

$$\delta_g = \max\left\{\begin{array}{l}\left|\frac{\alpha_i^{[\gamma]} - \alpha_i^{[\gamma-1]}}{\alpha_i^{[\gamma]}}\right|, \left|\frac{\beta_i^{[\gamma]} - \beta_i^{[\gamma-1]}}{\beta_i^{[\gamma]}}\right| \\ \left|\frac{k_{i-1}^{[\gamma]} - k_{i-1}^{[\gamma-1]}}{d_0^{[\gamma]}}\right|, \left|\frac{d_{i-1}^{[\gamma]} - d_{i-1}^{[\gamma-1]}}{d_0^{[\gamma]}}\right|\end{array}\right\}, \ i = \overline{1,n}.$$

Then following condition is tested:

$$\delta_g \le \varepsilon_g, \tag{9}$$

where ε_g = 0.01 is a permissible relative accuracy of the parameters estimation.

If condition (9) is false, the number γ is incremented and the test is repeated until a desired number δ_g will be found so that this condition (9) holds.

3.6 Testing frequencies determining

A testing frequencies determination method gives the lower bound of testing frequencies ω_l. The method which is used in this algorithm differs of method referenced in [7]. It has higher accuracy and speed of self-tuning, but it may give an error for particular cases.

If ω_l is found, all testing frequencies are determined by expression:

$$\lg\omega_k = \lg\hat\omega_l + (k-1)\frac{\lg\hat\omega_u - \lg\hat\omega_l}{n-1}, \quad k = \overline{1,n} \tag{10}$$

where $\hat\omega_u$ is an upper frequency, which is determined as:

$$\hat\omega_u = M\hat\omega_l,$$

where M is a frequency band (high-to-low testing frequency ratio).

4. Experimental investigations

4.1 Test bench

A test bench named FM-1 described in reference [7] has been used for an experimental investigation of DPI-3. It consists of single-board computer (ATH-660-128) which has both ADC and DAC inside, and, essentially, a physical plant model (PPM).

PPM [6] is an electrical device which consists of operational amplifiers and other passive components, so that its behavior corresponds to behavior of third-order dynamic system. PPM has a source of disturbance.

Continuous-time transfer function of PPM is:

$$W_{PPM}(s)=\frac{-203.5s+4966}{s^3+62.21s^2+2610s+4948}=$$
$$=1.004\frac{(-0.041s+1)}{(0.503s+1)(0.02^2s^2+2\cdot 0.603\cdot 0.02s+1)}=$$
$$=\frac{-203.5(s-24.4)}{(s+1.9868)(s^2+60.223s+2490.3)} \qquad (11)$$

4.2 Initial data

Following initial data, which is necessary to DPI-3 operation selected as:

- the output range limit of the plant $y\_=4$;
- the input range limit of the plant $u\_=4$;
- the plant order n = 3;
- the frequency band M = 30.

4.3 Results for small external disturbance

There is the external disturbance in the experiment which drives PPM so that its output as shown at the figure 2.

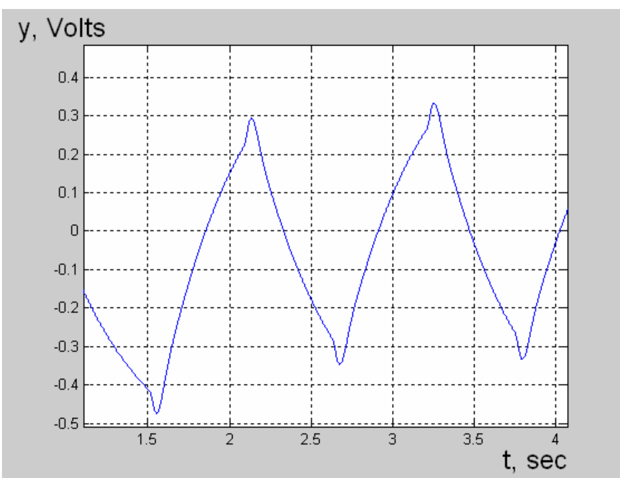

Figure 2. PPM output without the testing signal for small external disturbance

4.3.1 Low test frequency search

The low test frequency $\hat{\omega}_l=2.33$ radian/sec has been estimated through 2 test cycles. Elapsed time for search is 25.3 sec.

4.3.2 Self-tunings of test signal

The testing frequencies have been determined by expression (10) (radian/sec):

ω_1 = 2.3346; ω_2 = 14.008; ω_3 = 70.037.

The amplitudes have been self-tuned as, Volts:

ρ_1 = 0.181; ρ_2 = 0.728; ρ_3 = 2.69.

4.3.3 Identification

The identification procedure is shown on the figure 3. One can see that the transient of the testing signal is commensurable to the transient of the external disturbances.

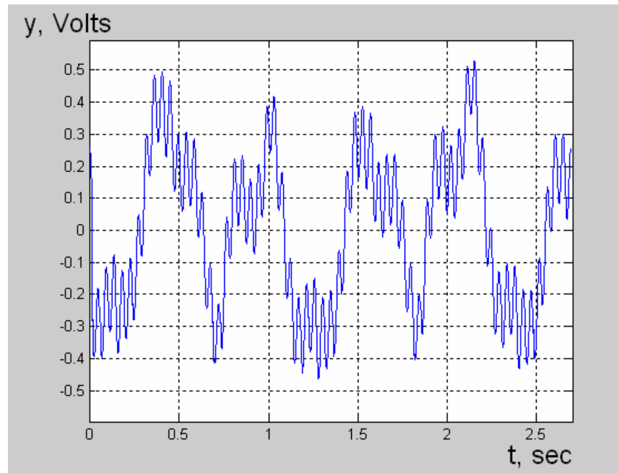

Figure 3. PPM output with the testing signal for small external disturbance

The identification took 60.06 sec. Its transient consists of 8 periods of the basic frequency ω_1. In results, the next transfer function has been estimated (this is a data of a protocol, which is created by program):

```
             0.400061 s^2 - 221.261085 s + 5436.678475
W(s) = ===================================================
          s^3 + 69.579723 s^2 + 2863.991467 s + 5594.392001
```

This transfer function may appear in next view:

$$\hat{W}_{PPM}(s)=\frac{0.400061s^2-221.261s+5436.7}{s^3+69.58s^2+2864s+5594.4}=$$
$$=0.972\frac{7.32\cdot 10^{-5}s^2-0.0407s+1}{(0.487s+1)(0.0192^2s^2+2\cdot 0.647\cdot 0.0192s+1)}=$$
$$=-221.261\frac{-0.0018s^2+s-24.57}{(s+2.052)(s^2+67.527s+2725.4)}.$$

4.4 Results for large external disturbance

There is the external disturbance in the experiment which drives PPM so that its output as shown at the figure 4.

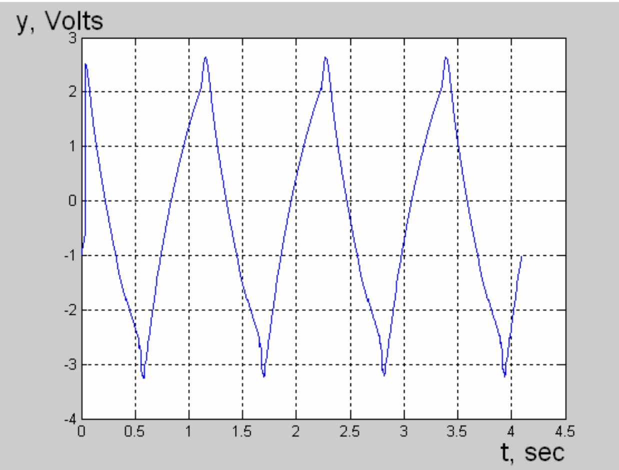

Figure 4. PPM output without the testing signal for large external disturbance

4.4.1 Low test frequency search

The low test frequency $\hat{\omega}_l = 1.75$ radian/sec has been estimated through 2 test cycles. Elapsed time for search is 25.3 sec.

4.4.2 Self-tunings of test signal

The testing frequencies have been determined by expression (10) (radian/sec):

ω_1 = 1.7515; ω_2 = 10.509; ω_3 =52.545.

The amplitudes have been self-tuned as, Volts:

ρ_1 = 0,196; ρ_2 = 1,36; ρ_3 = 2.04.

4.4.3 Identification

The identification procedure is shown on the figure 5. It can see that the transient of the testing signal is incommensurably less than the transient of the external disturbances.

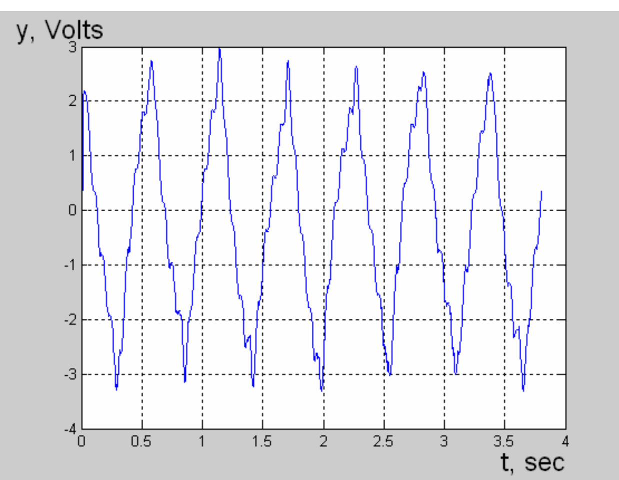

Figure 5. PPM output with the testing signal for large external disturbance

The identification took 215.7 sec. Its transient consists of 27 periods of the basic frequency ω_1. In results, the next transfer function has been estimated (this is a data of the protocol):

```
              -0.038889 s^2 - 243.577120 s + 5533.646338
W(s) = =====================================================
         s^3 + 72.693358 s^2 + 2925.393392 s + 5545.520874
```

This transfer function may appear in next view:

$$\hat{W}_{PPM}(s) = \frac{-0.039s^2 - 243.58s + 5533.7}{s^3 + 72.69s^2 + 2925.4s + 5545.6} =$$

$$= 0.998\frac{-7\cdot 10^{-6}s^2 - 0.044s + 1}{(0.5021s+1)(0.019^2 s^2 + 2\cdot 0.67\cdot 0.019s + 1)} =$$

$$= -243.58\frac{0.00016s^2 + s - 22.72}{(s+1.9915)(s^2 + 70.702s + 2784.6)}.$$

There are a gain-frequency, a logarithmic gain-frequency and a phase-frequency characteristics on figures 6, 7 and 8 accordingly.

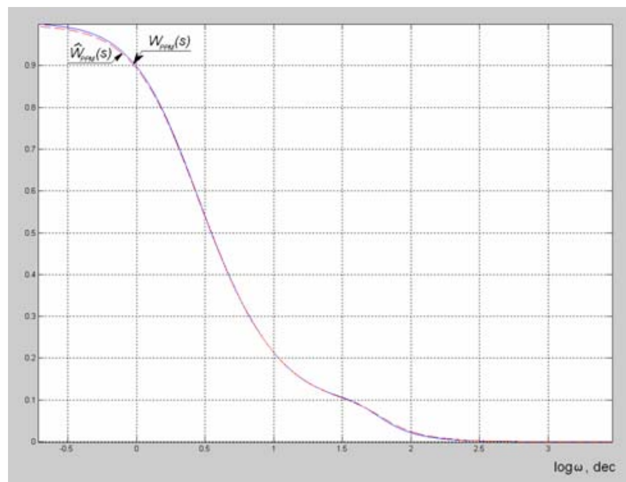

Figure 6. Gain-frequency characteristic of PPM and estimated

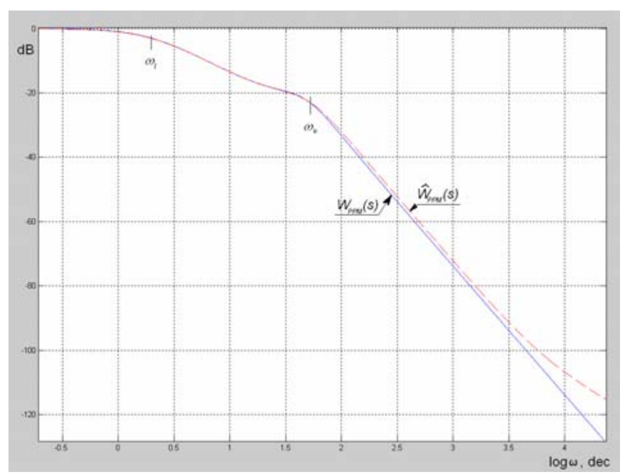

Figure 7. Logarithmic gain-frequency characteristic of PPM and estimated

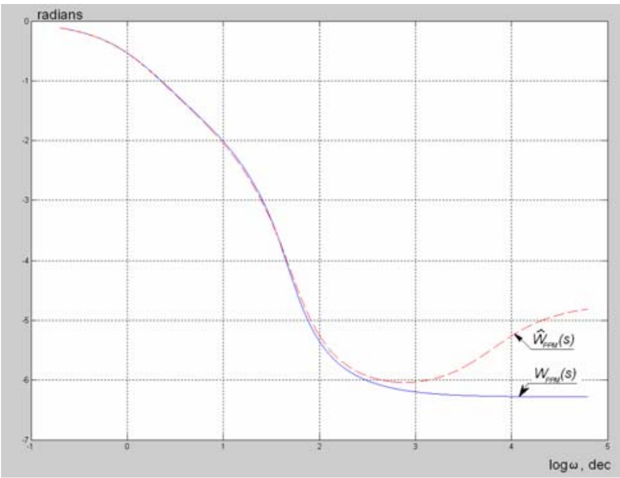

Figure 8. Phase-frequency characteristic of PPM and estimated

5. Conclusion

The identifier DPI-3 has been written in C language using the finite-frequency identification method.

The test bench has been designed for the experimental investigations.

The experimental investigations show a high accuracy of the identification and a reduction of the time of the identification.

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