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NON-INVASIVE PARAMETER IDENTIFICATION BY USING THE LEAST SQUARES METHOD

The paper presents an adapted least squares identification method for reduced-order parametric models. On the example of the open velocity loop, different model approaches were implemented in a motion control system. Furthermore, it is demonstrated how the accuracy of the method can be improved. Finally, experimental results are shown.

1. Introduction

For the correct tuning of servo controllers, there exist various tuning rules, whose application requires the exact knowledge about the controlled system. This knowledge can be gained by using several identification methods, which can be classified as follows.

Frequency domain based approaches generate a frequency response of the controlled system, for example by using pseudorandom binary signals (PRBS) as excitation. Significant parameters are visible in the frequency response of the system and can be determined manually and automatically [6, 11]. This kind of identification technique is also a part of various engineering systems for currently in use industrial motion control systems [4].

Identification methods in the time domain usually use specified test signals, like step-, impulse-, or relay functions to excite the controlled system. Depending on the type of input signal, the output signal includes information about the systems parameters, which can be extracted by using a wide range

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of identification approaches with different model orders [5, 6, 7, 8, 10, 12, 13, 14].

Both types of identification methods use defined test signals. Hence, they can not be applied during the operation of machine tools and manufacturing machines. As a result, special maintenance modes with down times are required. Sometimes, the identification process can not be carried out because of axis limitations or unacceptably high load situations. For example, the identification algorithm of currently used industrial servo controllers causes the drive to accelerate and decelerate several times with the maximum torque, which results in high mechanical stresses.

There also exist closed loop identification techniques, which do not require specific excitation signals, and therefore do not have these disadvantages. These non-invasive procedure use input signals of typical machine movements, in literature also termed as “natural excitation” [9, 15]. Hence, input signals (Command value) as well as the resulting output signals (Actual value) of the controlled system form the basis for the proposed identification method (Fig. 1).

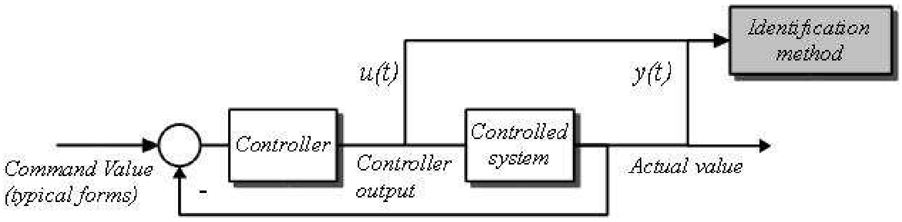

Fig. 1. Non-invasive identification method

The least squares method (LS), can be used as an invasive procedure (e.g. with PRBS excitation) with disturbance to the process and non-invasive procedure without any disturbance to the process. It does not require a specific input signal. The only requirement is a minimum power density in a specific frequency range.

The paper proposes a non-invasive parameter identification technique, using the least squares method, which will be introduced in the following section. In chapter three and four, the adaptation of the presented method to the velocity loop of an industrial motion controller system is demonstrated as well as an approach to improve the identification results by using data with smaller sample times. Experimental results are discussed in the fifth section. A conclusion follows in section six.

2. Least squares method

The least squares method is a standard method of regression analysis in several fields of engineering [1]. It is based on measured data and a time-discrete model transfer function where the number of measurements is far greater than the model order. As a result an overdetermined set of equations is received. The solution of a LS problem is the smallest sum of the squares of the errors. In this case, the parameters of the model function are called best fit [1, 3]. The solution of a least squares problem can be carried out non-recursively and recursively [1]. For the intended application on motion controllers, the recursive solution needs to be chosen. In addition, the order of matrix operations has to be as small as possible. The physical properties in the cascaded controlled system of electrical servo drives are known. They are represented by differential equations which can also be written as a reduced order parametric model by using the Laplace Transformation or the Discrete Laplace Transformation, respectively.

This expression for the system behaviour (or parts of the system behaviour) can be used directly as model function of the LS problem, as shown in Figure 2 [1, 7]. Hence, the estimated parameters of the model correspond with the physical values in the cascade structure.

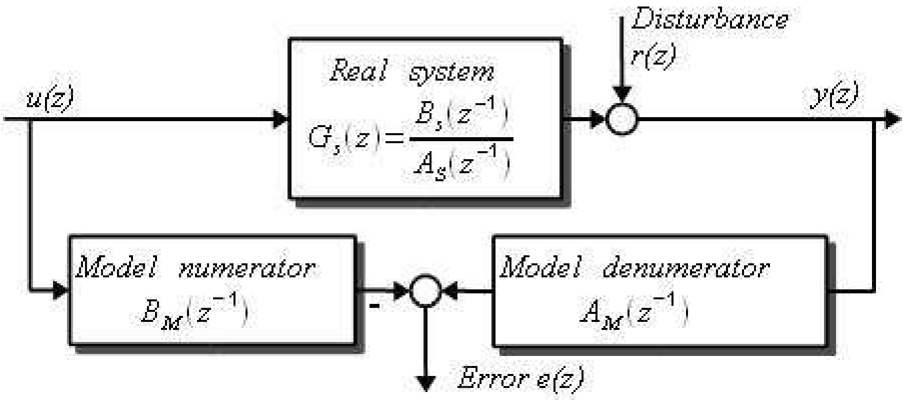

Fig. 2. Parametric model function for the least squares problem [1]

The error signal (e(z)) will only converge to zero if the model is equal to the real system and the disturbance signal (r(z)) is zero. In contrast to that, it will only reach a minimum value for real processes because of disturbances (r(z)), nonlinearities and inaccuracies in modelling.

3. Identification of velocity loop parameters

Industrial motion controllers are usually equipped with cascaded position control structures, containing a current loop, a velocity loop and a position loop. The proposed identification method has been applied to the velocity loop of such an industrial motion controller. The goal has been to derive a reduced order parametric model. Based on the structure of the closed velocity loop (Fig. 3), two possible model functions will be presented.

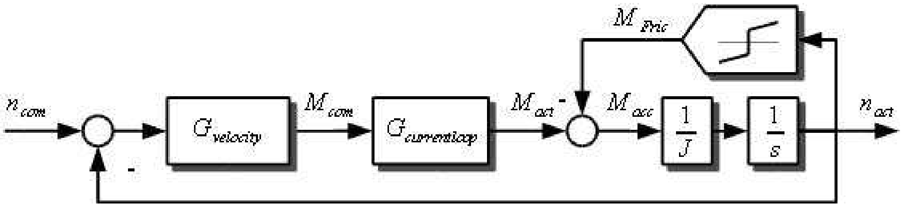

Fig. 3. Structure of the closed velocity loop

The chosen loop is essentially affected by the moment of inertia (J) and friction influences (M$_{fric}$) consisting of parameters for coulomb (M$_{RC}$) and a viscous friction (μ_R). According to Fig. 3, J can be calculated as follows:

$$\dot{n}_{act} = \frac{1}{J} \cdot M_{acc} = \frac{1}{J} \cdot (M_{act} - M_{fric}) \tag{1}$$

with:

$$M_{fric} = f(n_{act}) \tag{2}$$

Accessible values in the controller are the actual torque M$_{act}$ and the actual speed n$_{act}$. The acceleration torque M$_{acc}$ can not be measured. Hence, the estimation of the moment of inertia requires to additionally consider the friction influences M$_{fric}$, whereas the estimation can be carried out sequentially (SeqMA) or simultaneously (SimMA) according to Figure 4.

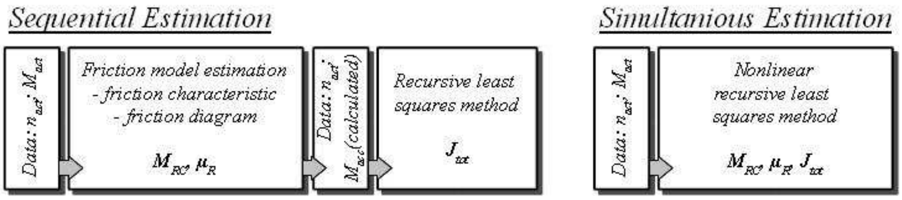

Fig. 4. Comparison of model approaches

Sequential Model Approach (SeqMA):

The first step in the SeqMA represents the separate estimation of the friction moment, depending on the velocity. Therefore, two methods were derived, which only use measured data without a priori knowledge.

The one method creates a characteristic curve for the friction moment (friction characteristic in Fig. 4). Therefore, phases in the trajectory without acceleration or deceleration are used, when the actual torque is equal to the friction moment. Consequently, data for different speed values and the related actual torques can be colleted and developed into a friction characteristic.

The second implemented method collects data for the friction moment for each segment of constant velocity. This friction diagram also distinguishes between positive and negative speed values. This reduces the hysteresis effects significantly. The SeqMA does not allow to carry out the identification method online. The separate estimation algorithms of the friction moment and moment of inertia refer to the same set of measured values, which causes a time delay.

In a second step, the moment of inertia J is estimated based on an integral system as follows:

$$y_k = y_{k-1} + a_1 \cdot u_{k-1} \tag{3}$$

Necessary values are:

sampled output signal at time k y_k ... actual speed n_{act}
sampled output signal at time k-1 y_{k-1} ... actual speed n_{act}
sampled input signal at time k-1 u_{k-1} ... actual torque M_{act}
parameter a1, which includes the moment of inertia J_{tot}

$$a_1 = \frac{60 \cdot T_{sample}}{J_{tot} \cdot 2\pi} \tag{4}$$

Equation 3 can be used to directly define the least squares problem. A comparison of both variants for the friction estimation of the SeqMA will be presented in section 5.

Simultaneous Model Approach (SimMA):

The SimMA considers the moment of inertia and the introduced friction model for the friction moment M_{fric}[7].

$$y_k = a_1 \cdot y_{k-1} + b_1 \cdot [u_{k-1} - M_{RC} \cdot sign(y_{k-1})] \tag{5}$$

with:

$$a_1 = e^{\frac{-\mu_{fric} \cdot T_{sample} \cdot 60}{J_{tot} \cdot 2\pi}} \qquad b_1 = \frac{1}{\mu_{fric}} \cdot \left(1 - e^{\frac{-\mu_{fric} \cdot T_{sample} \cdot 60}{J_{tot} \cdot 2\pi}}\right) \tag{6}$$

The total moment of inertia (J_{tot}), the constant part of friction moment (M_{RC}) and friction coefficient (μ_{fric}) are estimated by the least square method. Both parameters of the friction moment are only valid for the specific area of operation, which was affected in the axis movement.

The SimMA has been implemented in two different versions. Apart from equation 5 a decoupled variation was derived (eq. 7), where each physical parameter only affects one parameter of the SimMA. This kind of procedure has been chosen to determine whether the manner of generating the model has an influence on the convergence of parameters.

$$y_k = y_{k-1} + a_1 \cdot [u_{k-1} - M_{RC} \cdot sign(y_{k-1})] - \mu_{fric} \cdot y_{k-1} \tag{7}$$

with:

$$a_1 = \frac{60 \cdot T_{sample}}{2\pi \cdot J_{tot}} \tag{8}$$

The SeqMA as well as the SimMA approach were implemented on an industrial motion controller using the recursive least squares method [1]. The highest order of necessary matrix operations is 3. Hence, the calculation can be carried out on typical motion controllers.

4. Access point to drive parameters with Simotion

The identification method has been implemented and tested on a SIEMENS motion controller SIMOTION D445 with a SINAMICS drive system. Both components are connected via Profibus Integrated, which uses the Profinet Telegram. The sample time of the algorithms for the identification method is limited by the motion controller to 500μs. The SINAMICS components can be sampled with down to 62.5μs, the default sample time is set to 125μs (Fig. 4). The required values (actual torque, actual speed) are measured in the drive system and sent to the D445 via Profinet Telegram. Hence, the algorithm is processing this data with a sample time of 500μs. In order to reduce influences of disturbances and measurement errors as well as to improve the convergence of the LS problem, it would be beneficial to use drive data in a sample time of 125μs. An access point to this data was found, using a trace recorder, which is located in the SINAMICS system.

As shown in Fig. 5, a bypass for drive data has been created. The trace recorder can not only be controlled by the engineering system SIMOTION SCOUT, but also via structured text (ST) instructions. The parameterization, start commands, stop commands and data read operations can be carried out automatically as a part of the ST implementation. The recorded data is stored in arrays and can be read by the motion controller. Thus, the identification method can be applied using drive data. Due to the required data storage, the algorithm runs quasi-online but with a higher accuracy (Fig. 6).

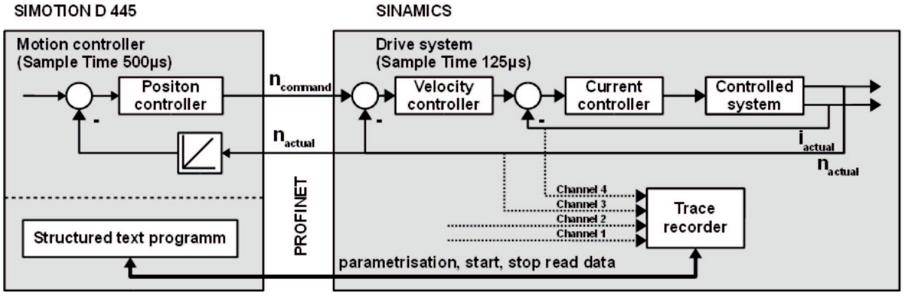

Fig. 5. Access point to drive parameters

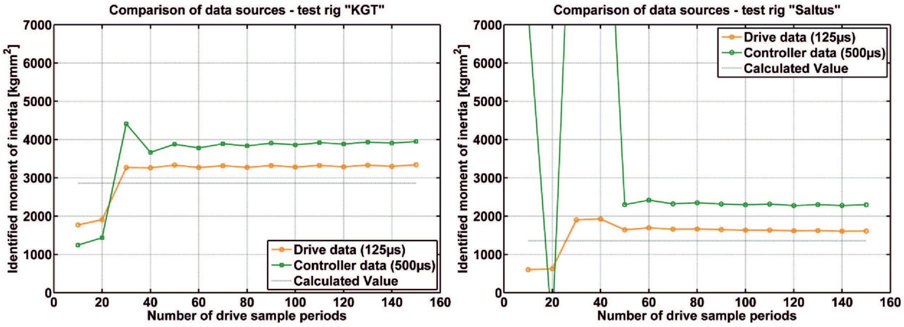

Fig. 6. Comparison of data sources with different sample times

5. Experimental results

The identification method has been implemented on Siemens hardware. Two test rigs with known moments of inertia have been taken to test and improve the algorithms (Fig. 7).

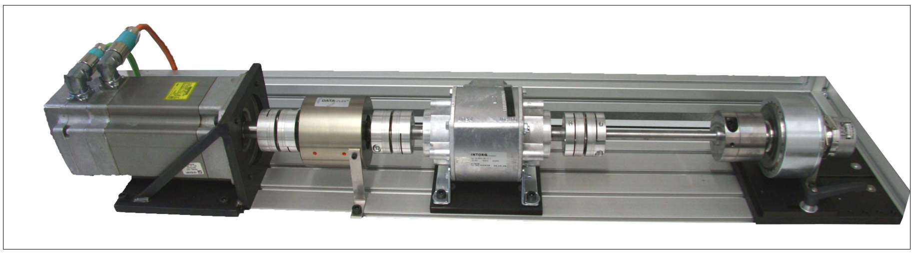

Fig. 7. Test rig ”Saltus”

Experiments with stair functions for the command speed n_{com} have been carried out. The variable parameters have been the speed levels, the speed controller parameters and the duration of measurement. The experimental results for the identification method with the introduced model approaches (SeqMA, SimMA) are illustrated in Figure 8. For the test rig “KGT” on the left side and “Saltus” on the right side, the identified moments of inertia are displayed for different command speeds n_{com}.

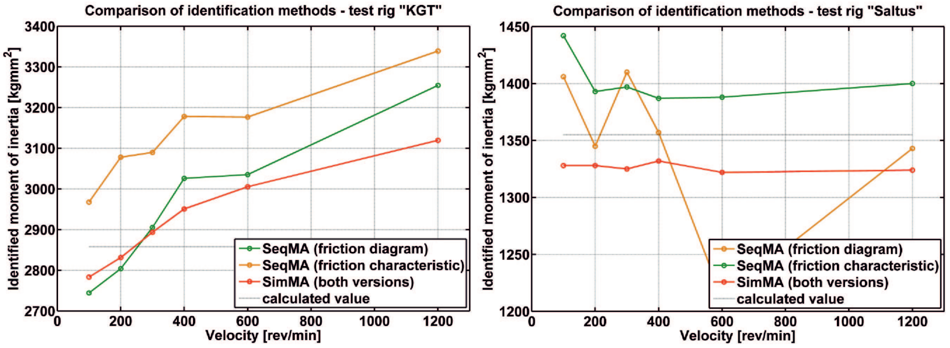

Fig. 8. Results of the identification method

The results of the SimMA in the shown variation are nearly identical for both test rigs. Consequently, only one set of data is displayed for the SimMA. Both versions of the SeqMA show noticeable errors. On the left side of Figure 8 (test rig “KGT”) a dependence on the speed level is also visible for all model approaches. The SimMA achieves the smallest variance for all performed experiments.

The reason for the errors may result from nonlinearities, like hysteresis effects in friction. These secondary effects are typical for electric servo drives. Due to the simultaneous parameter estimation and the ability to separate the acceleration torque from the friction moment, the SimMA provides better results than SeqMA, which has been confirmed by the experiments.

6. Conclusion

The presented method is suitable for the identification of controlled systems. Investigations have been carried out, where the algorithm has been adapted to the velocity loop of a motion controller system. The experimental results have shown that the SimMA provides better results than the SeqMA. The final result of the identification process is a nonlinear plant characteristic, following the equations 5 and 6.

The velocity controller can be tuned by making use of existing tuning rules and identified parameters. These parameters are provided by an algorithm which is non-invasive. Hence, the algorithm can be processed simultaneously to the typical movements of the machine. The change in the parameters is recognized immediately. As consequence, the adjustment to the controller or maintenance operations can be performed. Further research will be carried out in order to improve the algorithm and to adjust it to other loops of the cascade structure. An implementation on numeric control systems for machine tools will be realized as well.

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Nieinwazyjna identyfikacja parametrów przy wykorzystaniu metody najmniejszych kwadratów

Streszczenie

W artykule przedstawiono metodę identyfikacji, wykorzystującą metodę najmniejszych kwadratów, przystosowaną do modeli parametrycznych ograniczonego rzędu. Na przykładzie otwartej pętli regulacji prędkości zilustrowano różne podejścia do modelowania systemów sterowania. Zademonstrowano ponadto, jak można poprawić dokładność metody. W końcowej części pracy przedstawiono wyniki doświadczalne.