

## CLOSID - A MATLAB TOOLBOX FOR CLOSED-LOOP SYSTEM IDENTIFICATION

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Abstract: A closed-loop system identification toolbox for MATLAB is presented, including a user-friendly graphical user interface. The toolbox is written as an add-on to MathWork's System Identification Toolbox (SITB), version 4.0, and suited for Matlab version 5.2. With this CLOSID toolbox it is possible to identify linear models on the basis of experimental data obtained from a plant that is operating under the presence of a controller, incorporating reference signal and controller information in the identification. It comprises several closed-loop identification methods (both classical and more recent ones), and includes tools for evaluation of closed-loop model and controller properties.

Keywords: System identification, closed-loop identification, Matlab-toolbox

### 1. INTRODUCTION

For the identification of (linear) systems on the basis of experimental data there are well-supported user-friendly tools available. Next to the commercially available industrial packages as ADAPT<sub>x</sub> (by Adaptic Inc.), ISID (by ISI) and Tai-Ji ID (by Tai-Ji Control) there is in particular Mathwork's System Identification Toolbox SITB, version 4, which is widespread among universities and industries. This latter toolbox is equipped with a graphical user interface, enabling the user to identify and validate models in different types of model structures. Additionally there is users' support in terms of graphical tools for model evaluation as well as support for e.g. bookkeeping of

identified models. In the tools that are currently available, there is generally no possibility to include particular knowledge of external excitation signals and/or implemented controllers when the measurement data are obtained under closed-loop conditions. Besides, it has been motivated in the literature that dedicated closed-loop identification methods can outperform the classical (direct) approach in which the presence of a controller during experimentation is actually neglected.

In this paper a Matlab toolbox for closed-loop system identification will be presented that extends the functionality of the System Identification Toolbox SITB in the following ways:

- It provides a graphical user interface supported tool for identification of models from closed-loop observations;
- It enables the use of external excitation signals as well as of knowledge of the controller present in the loop;

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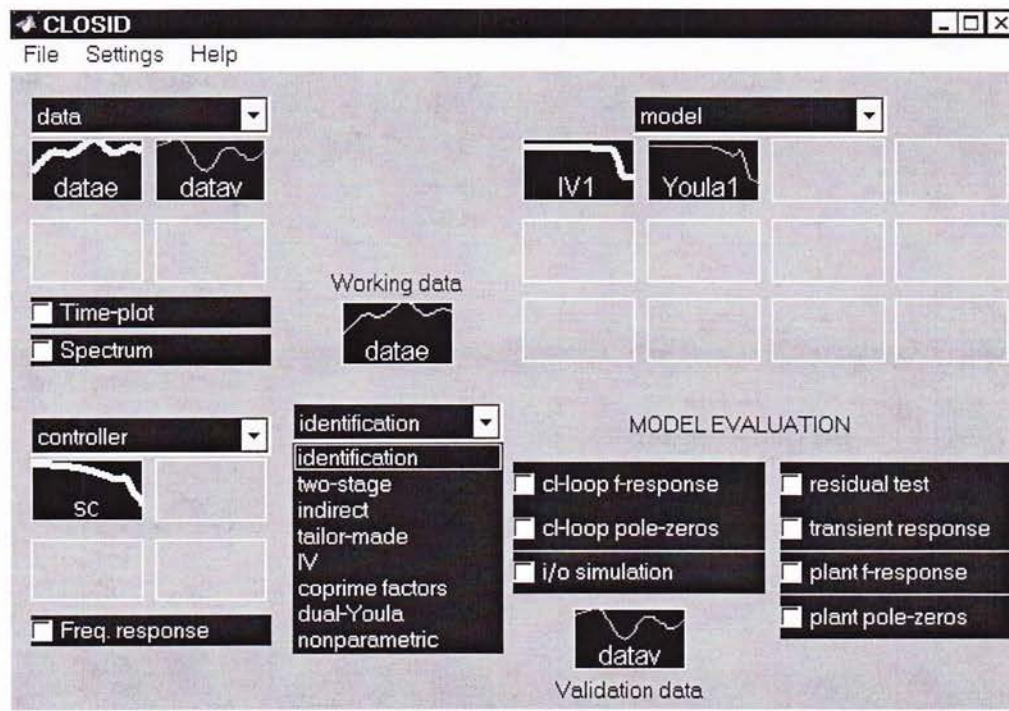


Fig. 1. CLOSID - Main window

- It allows the separate identification of plant models and noise models;
- It is written as an add-on tool to SITB, meaning that for the actual estimation part of the closed-loop identification methods, SITB is automatically opened and applied, while in the CLOSID tool the data processing and the (closed-loop) model processing is performed. Therefore full performance and flexibility of the estimation methods in SITB is retained.
- It enables simple evaluation and validation of models in terms of their closed-loop properties, as e.g. closed-loop residual tests, sensitivity functions, complementary sensitivities, closed-loop poles, etc.

The experimental setup to be considered is depicted in Figure 2.

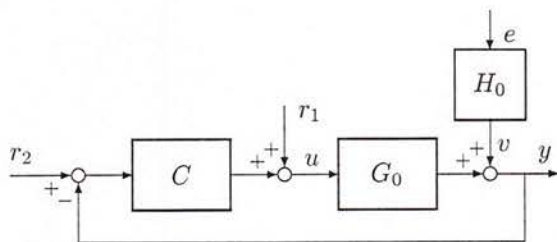


Fig. 2. Closed-loop configuration.

In this configuration  $r_1$  and  $r_2$  are external excitation signals, uncorrelated to the filtered white noise disturbance signal  $v = H_0 e$ . The sensitivity function of the closed-loop is denoted by  $S_0 = (1 + CG_0)^{-1}$ .

## 2. TOOLBOX SET-UP

The graphical user interface of the CLOSID toolbox provides a main window as shown in Figure 1.

The main window shows the following basic parts:

- a **data board** on the left upper part, where imported data sets are represented by colored line-icons, that can be selected by a mouse action.
- a **controller board** on the left lower part, where imported controllers are represented by colored line-icons, with similar selection options.
- an **identification menu** in the middle; this pop-up menu provides the user with a list of identification methods that can be applied.
- a **model board** on the right upper part, showing identified or imported models of the plant to be identified.
- a **model evaluation** area, containing check boxes for the application of several (closed-loop) evaluation procedures for the models on the model board possibly in combination with controllers selected from the controller board.

Additionally there are selection icons for “working data”, reflecting the data that are used for identification, and for “validation data”, reflecting the data that are used for all model evaluations. Besides the controller board, the composition of the CLOSID main window is very similar to the main window of the SITB. This controller board is



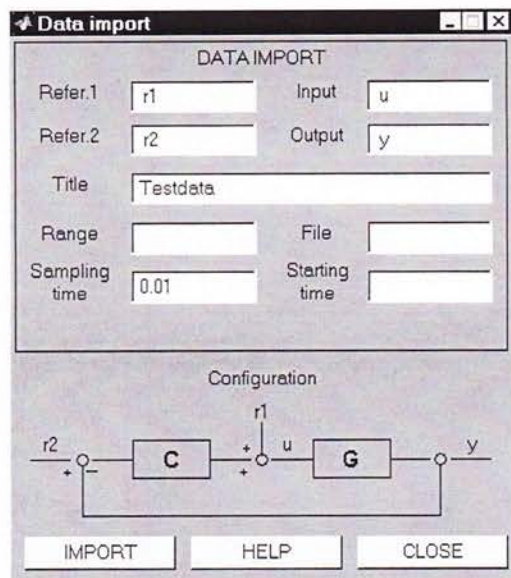


Fig. 3. CLOSID - Data import window.

required, as some of the closed-loop identification methods require information on the implemented controller. Additionally, this enables the user to evaluate the models in the presence of a (user-chosen) feedback controller.

Data sets, controllers and models can be imported from the MATLAB workspace, through selecting the respective pop-up menus for data, controller and model.

A data set is composed of experimental data  $\{u, y\}$  over a given time horizon, together with either one of the external excitation signals  $r_1$  and/or  $r_2$ . Data sets can be viewed on screen in terms of time sequences and power spectra, by clicking on the corresponding check boxes under the data board. Figure 3 shows the "Data Import" import window, through which data can be imported from the Matlab workspace. Models, as well as controllers, can be imported from and exported to the MATLAB workspace, in different formats.

### 3. CLOSED-LOOP IDENTIFICATION METHODS

The CLOSID toolbox contains six identification methods for parametric model identification, and one nonparametric method. The methods are denoted by

- (1) **two-stage** method,
- (2) **indirect** identification,
- (3) identification with a **tailor-made** parametrization,
- (4) **IV** (instrumental variable)-method,
- (5) **coprime factor** identification,
- (6) identification in the **dual-Youla/Kucera** parametrization,

- (7) **non-parametric** (spectral) estimation.

For details on the different methods, one is referred to the references, in particular to Van den Hof (1997) and Forssell and Ljung (1999).

The methods are all characterized by three steps, focussed on a specific closed-loop object that is going to be identified. The three steps are clearly indicated in the several identification windows and are characterized as follows.

- **Construction/selection of auxiliary signals.**

A first step of choosing - out of the available reference, input and output signals, the appropriate signals for identification of a particular transfer function object.

- **Identification.**

A second step of actual identification of the considered object, by estimating parameters through a least-squares identification criterion.

- **Calculate plant model.**

From the identified object a plant model is constructed/calculated and this plant model is copied to the CLOSID model board.

By choosing one of the identification methods from the **identification** pop-up menu, a particular window is opened, displaying the three steps mentioned above.

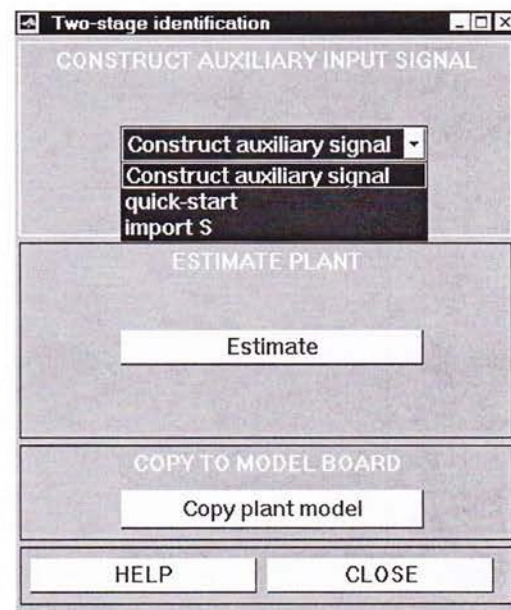


Fig. 4. CLOSID - Identification window for two-stage identification method.

The first step is trivial for some methods, but requires a separate identification for some others. In these latter cases, quick-start options provide a simple means to construct the appropriate signals. Apart from the "tailor-made" and the "IV" approach, all parametric identification methods will



perform the second step by opening MATLAB's SITB automatically, copying the appropriate signals from the CLOSID toolbox to the data board of SITB, allowing the user to identify the required transfer function object in the "open-loop" toolbox. In all of these situations, the second step is an identification problem that can be handled by the algorithms that are available in SITB.

When an appropriate model is identified and validated in SITB, it can be copied to the CLOSID window, by pushing the **Calculate and copy plant model** in the CLOSID identification window. This third step then transfers the identified object to a plant model on the CLOSID model board, where closed-loop properties of the model can be evaluated. As an illustration the identification window of the two-stage method is shown in Figure 4.

#### 4. SYNOPSIS OF IDENTIFICATION METHODS

A brief overview is given of the characteristics of the different parametric methods. Note that all methods require the presence of a persistently exciting reference signal, which can be either  $r_1$  or  $r_2$  (see figure 2).

##### 4.1 Two-stage method

In the first stage the transfer function between reference signal  $r_1$  and input signal  $u$  (sensitivity function) is estimated, leading to an accurate (high-order) model  $\hat{S}$ . With this estimate a noise-free input signal is simulated according to  $x(t) := \hat{S}(q)r_1(t)$ . For this estimation and simulation a quick-start option is available in the toolbox.

In the second stage the noise-free input  $x$  is used together with the output signal  $y$  to identify a plant model in SITB.

##### 4.2 Indirect method

The closed-loop transfer function between  $r_1$  and  $y$  is estimated ( $\hat{R}$ ). By using information on the implemented controller  $C$ , an open-loop plant model is reconstructed from  $\hat{R}$ , according to

$$\hat{G}(q) = \frac{\hat{R}}{1 - C\hat{R}}.$$

If the controller is stable, then  $\hat{G}$  is guaranteed to be stabilized by  $C$ . The model order of  $\hat{G}$  will generically be equal to the sum of orders of  $\hat{R}$  and  $C$ .

##### 4.3 Tailor-made parametrization method

The closed-loop transfer function between  $r_1$  and  $y$  is estimated, using a dedicated parametrization in terms of the parameters of the open-loop plant model and the known controller  $C$ . The plant model  $G(q, \theta)$  appears in the closed-loop transfer function as

$$\frac{G(q, \theta)}{1 + C(q)G(q, \theta)}.$$

##### 4.4 IV-method

A basic instrumental variable estimate is constructed using  $u$  and  $y$  as measured data, and employing  $r_1$  or  $r_2$  as instrumental signal.

##### 4.5 Coprime factor method

The closed-loop transfer functions between (a filtered version of)  $r_1$  and/or  $r_2$  (as input) and  $(y, u)$  (as outputs) are estimated, and an open-loop plant model is obtained by taking the quotient of the two estimates.

Using an appropriate filter operation on  $r_1$  and/or  $r_2$  the order of the two objects to be estimated can be minimized. This filter can be realized on the basis of an auxiliary plant model  $G_x$  for which a quick-start estimation procedure is available.

##### 4.6 Dual-Youla/Kucera method

The closed-loop transfer function between (a filtered version of)  $r_1$  and/or  $r_2$  (as input) and a filtered version of  $u + Cy$  (as output) is estimated, creating an object that is stable if and only if the closed-loop system is stable. By recalculation, an open-loop plant model can be reconstructed. This method is a generalization of the indirect method, being also applicable to situations of unstable plants and/or controllers.

##### 4.7 Non-parametric estimation

The nonparametric identification method identifies spectral models for the one input, two output transfer from  $r$  ( $r_1$  or  $r_2$ ) to  $col(y, u)$ , and constructs a plant model by taking the quotient of the two scalar nonparametric estimates.

## 5. MODEL EVALUATION

Once a model is estimated and made available on the model board, several open-loop and closed-loop model properties can be evaluated. This is done using the seven **Model evaluation** options at the right-lower part of the main **Closid** window, figure 1. Example outputs of these tests are provided in Figures 5 and 6.

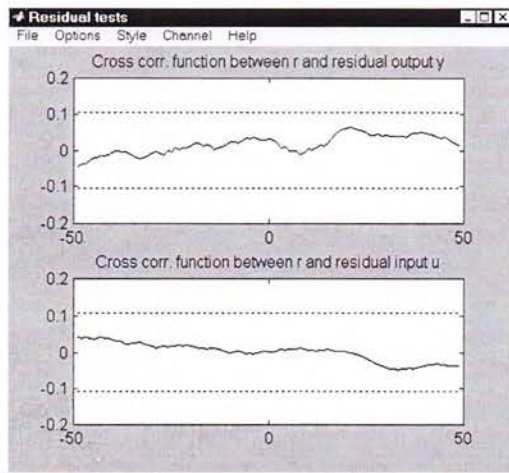


Fig. 5. Closed-loop residual test.

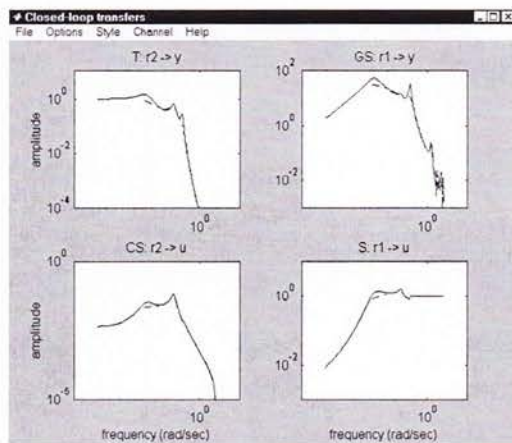


Fig. 6. Closed-loop transfer functions of nonparametric model (dashed) and parametric model (solid).

## 6. SUMMARY

A MATLAB toolbox has been presented for closed-loop system identification on the basis of time domain data. It has been designed as an add-on to Mathworks' System Identification Toolbox (SITB). A graphical user interface with a layout similar to the SITB supports the user, and facilitates exchange of models between the SITB and the current toolbox. In its current version the graphical user interface supports the identification of SISO models; the provided MATLAB m-files are implemented to handle also multivariable models.

The tool is available to the public domain at the web-site [www.tn.tudelft.nl/mmr](http://www.tn.tudelft.nl/mmr).

## 7. REFERENCES

- Forssell, U. and L. Ljung (1999). Closed-loop identification revisited. *Automatica*, **35**, 1215-1241.
- Gevers, M. (1993). Towards a joint design of identification and control? In: *Essays on control: Perspectives on the Theory and its Applications*, Birkhäuser, Boston, pp. 111-151.
- Ljung, L. (1999). *System Identification: Theory for the User*. Prentice-Hall, Englewood Cliffs, NJ, 2nd edition.
- Ljung, L. (1995). *System Identification Toolbox User's Guide*, Version 4.0, The Mathworks, Inc., Natick, Mass., 1995.
- Söderström, T. and P. Stoïca (1989). *System Identification*. Prentice-Hall, Hemel Hempstead, U.K.
- Van den Hof, P.M.J. and R.J.P. Schrama (1995). Identification and control - closed-loop issues. *Automatica*, **31**, 1751-1770.
- Van den Hof, P.M.J. (1997). Closed-loop issues in system identification. In: Sawaragi and S. Sagara (Eds), *System Identification (SYSID'97)*, Proc. 11th IFAC Symp. System Identification, Kitakyushu, Japan, 8-11 July 1997. IFAC Proceedings Series, Vol. 3, pp. 1547-1560.