

CONTSID: a Matlab toolbox for data-based modelling of continuous-time dynamic systems

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Abstract

This paper describes the CONTinuous-Time System Identification (CONTSID) toolbox to be run with MATLAB which includes time-domain identification methods for estimating continuous-time models directly from sampled data. The new version aims at extending the available methods to handle wider practical situations in order to enhance the application field of the CONTSID toolbox. The toolbox now includes routines to solve errors-in-variables and closed-loop identification problems, as well as non-linear continuous-time model identification techniques.

Keywords: continuous-time model, discrete-time data, Matlab toolbox, software tools, system identification

1 Key features

The motivation for developing the CONTSID toolbox for MATLAB[®] was first to fill in a gap, since no software support was available to serve the cause of direct time-domain identification of continuous-time linear models but also to provide the potential user with a platform for testing and evaluating these data-based modelling techniques. The CONTSID toolbox was first released in 1999. It has gone through several updates, some of which have been reported at recent symposia and now in a book [5]. The key features of the CONTSID toolbox are:

- it supports most of the time-domain methods developed over the last thirty years for identifying linear dynamic continuous-time parametric models from measured input/output sampled data;
- it provides transfer function and state-space model identification methods for single-input single-output (SISO) and multiple-input multiple-output (MIMO) systems, including both traditional and more recent approaches;
- it can handle mild irregularly sampled data in a straightforward way;
- it may be seen as an add-on to the system identification (SID) toolbox for MATLAB[®]. To facilitate its use, it has been given a similar setup to the SID toolbox;
- it provides a flexible graphical user interface (GUI) that lets the user analyse the experimental data, identify and evaluate models in an easy way.

The latest version of the CONTSID toolbox has the following three major additions:

- it supports errors-in-variables CT transfer function model identification;
- it provides routines to estimate linear CT transfer function model in closed loop;
- it includes methods to identify nonlinear CT Hammerstein models.

2 Parametric estimation methods

The CONTSID toolbox includes routines to identify CT linear transfer function and state-space models directly from regularly or irregularly time-domain sampled data [3].

2.1 Transfer function models

The toolbox supports transfer function models of the following forms

$$y(t_k) = \sum_{i=1}^m G^i(p)u^i(t_k) + H(q)e(t_k) \quad (1)$$

where p denotes the differential operator and q is the standard forward shift operator; $u^i(t_k)$ and $y(t_k)$ represent the deterministic inputs and noisy output at time instant t_k , respectively. $e(t_k)$ is a zero-mean DT white Gaussian sequence. Here, the model of the basic dynamic system is in continuous time, while the associated additive noise model is a discrete-time, autoregressive moving-average (ARMA) process. The elements $G_i(p)$ and $H(q)$ are rational according to

$$G^i(p) = \frac{B^i(p)}{F^i(p)}, \quad H(q) = \frac{C(q^{-1})}{D(q^{-1})} \quad (2)$$

with

$$B^i(p) = b_1^i p^{n_b-1} + b_2^i p^{n_b-2} + \dots + b_{n_b}^i, \quad (3)$$

$$F^i(p) = p^{n_f} + f_1^i p^{n_f-1} + \dots + f_{n_f}^i, \quad n_f \geq n_b - 1 \quad (4)$$

$$C(q^{-1}) = 1 + c_1 q^{-1} + \dots + c_q q^{-n_c} \quad (5)$$

$$D(q^{-1}) = 1 + d_1 q^{-1} + \dots + d_p q^{-n_d} \quad (6)$$

Various estimation methods for identifying CT ARX, CT hybrid OE and hybrid Box-Jenkins models are implemented in the CONTSID toolbox [3].

2.2 State-space models

Continuous-time state-space models considered in the CONTSID toolbox take the form

$$\begin{cases} \dot{x}(t_k) = Ax(t_k) + Bu(t_k) \\ y(t_k) = Cx(t_k) + Du(t_k) + \xi(t_k) \end{cases} \quad (7)$$

where $u(t_k) \in \mathbb{R}^{n_u}$ is the input vector and $y(t_k) \in \mathbb{R}^{n_y}$ the output vector and $x(t_k) \in \mathbb{R}^n$ is the state vector at time t_k , $\xi(t_k) \in \mathbb{R}^{n_y}$ is the possibly coloured output noise vector.

Two types of approaches for CT state-space model identification are available in the CONTSID toolbox. A first family of techniques relies on the *a priori* knowledge of structural indices, and considers the estimation of CT canonical state-space models. From the knowledge of the observability indices, the canonical state-space model can, in a straightforward way, be first transformed into an equivalent input–output polynomial description that is linear-in-its-parameters and therefore more suitable for the parameter estimation problem. A preprocessing method may then be used to convert the differential equation into a set of linear algebraic equations in a similar way to that for CT ARX type of models. The unknown model parameters can finally be estimated by LS or IV-based algorithms.

A second class of state-space model identification schemes is based on the *subspace-estimation techniques*. Most efficient data-based modelling methods, discussed so far, rely on iterative, non-linear optimisation or IV-type methods to fit parameters in a preselected model structure, so as to best fit the observed data. Subspace methods are an alternative class of identification methods that are ‘one-shot’ rather than iterative, and rely on linear algebra. Moreover, these subspace methods are attractive since canonical forms are not required, while fully parameterised state-space models are estimated directly from sampled I/O data. Most commonly known subspace methods were developed for DT model identification. The association of the more efficient preprocessing methods with subspace methods of the 4SID family has been implemented in the toolbox.

2.3 New developments

Recent developments aimed at extending the available methods to handle wider practical situations in order to enhance the application field of the CONTSID toolbox. The latest version of the toolbox includes routines to solve:

- errors-in-variables problems [8, 9], where the output and the input are corrupted by noise;
- closed-loop identification [6] problems when the controller is known or not using an optimal instrumental variable technique to handle hybrid Box-Jenkins model estimation;
- identification of non linear Hammerstein CT Box-Jenkins models [7].

More details may be obtained in [4].

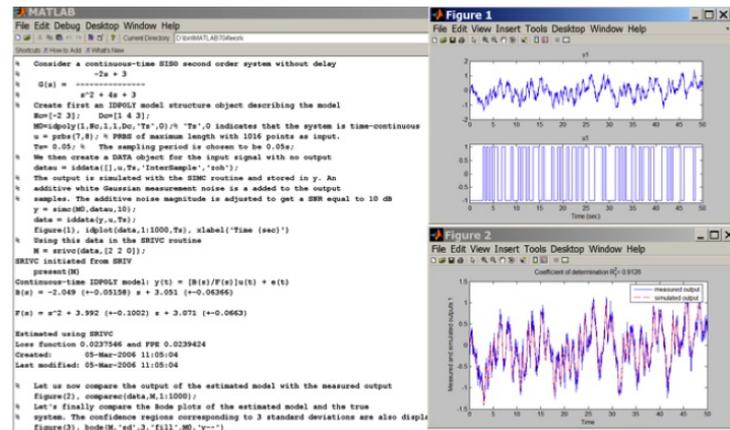


Fig. 1: Matlab command line and programming language

3 Working with the CONTSID toolbox

3.1 The CONTSID toolbox: a brief description

The CONTSID toolbox is compatible with MATLAB® versions 7.x. Two external commercial toolboxes are required: the Control toolbox and the SID toolbox. The current version can be considered as an add-on to the SID toolbox and makes use of the `iddata`, `idpoly` and `idss` objects used in the SID toolbox. A fully functional version of the toolbox for a three month evaluation period can be downloaded from <http://www.cran.uhp-nancy.fr/contsid/>.

All available parametric model estimation functions share the same command structure

```
m = function(data,modstruc)
```

The input argument `data` is an `iddata` object that contains the output- and input-data sequences along with the sampling time and inter-sample behaviour for the input, while `modstruc` specifies the particular structure of the model to be estimated. The specific parameters depend on the preprocessing method used. The resulting estimated model is contained in `m`, which is a model object that stores the various usual information. The function name is defined by the abbreviation for the estimation method and the abbreviation for the associated preprocessing technique, as for example, `IVSVF` for the instrumental variable-based state-variable filter approach or `SIDGPMF` for subspace-based state-space model identification GPMF approach.

Note that help on any CONTSID toolbox function may be obtained from the command window by invoking classically `help name.function`.

In addition to the parameter estimation routines, the toolbox also includes tools for generating excitation signals, selecting the model orders as well as for evaluating the estimated CT model properties.

The main demonstration program called `idcdemo` provides several examples illustrating the use and the relevance of the CONTSID toolbox approaches. These demos also illustrate what might be typical sessions with the CONTSID toolbox.

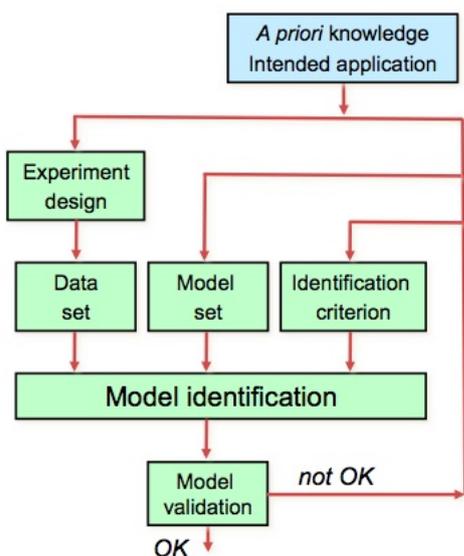


Fig. 3: Flexible Graphical User Interface

3.2 The CONTSID GUI

The other way to work with the CONTSID toolbox is to use the GUI (Graphical User Interface). The CONTSID GUI provides a main window, as shown in Figure 2, which is divided into three basic parts:

- a data panel on the left part where data sets can be imported, plotted, pre-treated and selected;
- a model estimation panel in the middle where different model structures and identification methods to directly estimate a CT transfer function model can be tested;
- a model validation panel in the right part where basic properties of the identified model can be examined.

The CONTSID GUI can be started by typing `contsidgui` in the Matlab command window.

The GUI allows the user to easily apply the iterative process of system identification (see Figure 3).

4 A few successful application examples

4.1 Effective rainfall-flow modelling

The modeling purpose here was flood forecasting and warning. The data or process features are:

- one of the most challenging problems in hydrology;
- non standard property of the nature of the noise: heteroscedastic (its variance changes radically over time);
- effective rainfall, i.e. the rainfall that is effective in causing variations in river flow;
- daily data from the Canning, an ephemeral river in Western Australia.

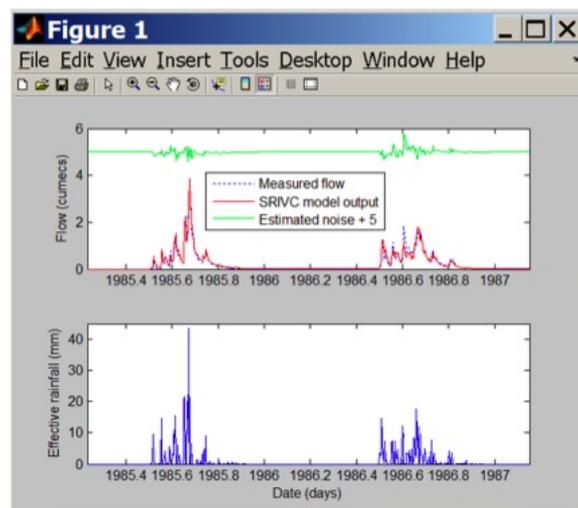


Fig. 4: Rainfall-flow modeling

The identification technique used is optimal IV method (srive) and one of the main interest of the analysis is the interpretation of the identified model in a physically meaningful manner.

The following model is obtained from the data analysis:

$$y(t_k) = \frac{b_0 p^2 + b_1 p + b_2}{p^2 + a_1 p + a_2} u(t_k) + \xi(t_k) \quad (8)$$

$$y(t_k) = \left[0.016 + \frac{0.14}{1 + 2.57p} + \frac{0.11}{1 + 18.71p} \right] u(t_k) + \xi(t_k) \quad (9)$$

The three parts of this model are easy to interpret as follows:

- the instantaneous pathway reflects rainfall affecting flow within one day;
- the quick-flow pathway reflects surface water processes;
- the slow-flow pathway reflects ground water effects.

Form Figure 4, it can be seen that the estimated and measured data coincide very well.

4.2 Multivariable winding process modeling

The main purpose of the identification of this process was the control system design. The process characteristics are:

- 3 inputs: $I * 1$: motor current setpoint 1, $S * 2$: motor angular speed setpoint 2, $I * 3$: motor current setpoint 3;
- 3 outputs: $T1$: tension between motors 1 and 2, $S2$: motor angular speed 2, $T3$: tension between motors 2 and 3;
- fast sampled data, the sampling period is equal to 10 ms;
- pilot plant.

The identification technique used here is the subspace based GPMF method (`sidgpmf`). The data are represented on Figure 5 and the results on Figure 6 where we can see that the estimated models are really efficient.

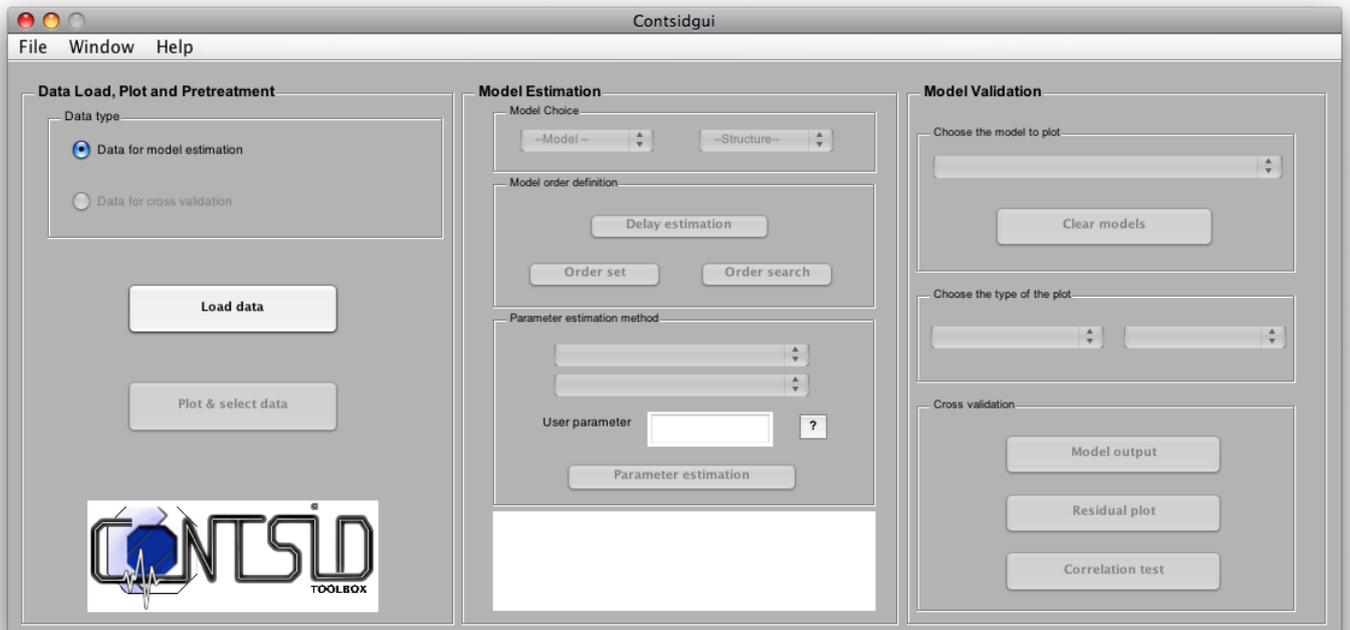


Fig. 2: Flexible Graphical User Interface

4.3 Modeling of photodynamic tumor therapy

Photodynamic therapy (PDT): an emerging therapy for dis-plastic tissues such as cancers. PDT involves selective uptake and retention of a photosensitive drug in a tumor, followed by irradiation with light at an appropriate wavelength.

The modeling purpose is a better control PDT therapeutic effectiveness.

The data or process features are:

- irregularly sampled data and only few data samples;
- step excitation signals.

The identification technique used is the optimal IV method (srivc). The results are given in Figure 7. The measured and simulated data coincide well.

5 What does the CONTSID toolbox have to offer?

5.1 Key features

The CONTSID toolbox methods offer several advantages over the alternative DT methods:

- they directly provide differential equation models whose parameters can be interpreted immediately in physically meaningful terms. As a result, they are of direct use to scientists and engineers who most often derive models in differential equation terms based on natural laws and who are much less familiar with black-box discrete-time models;
- the estimated model is defined by a unique set of parameter values that are not dependent on T_s ;

- there is no need for conversion from discrete to continuous-time required in the indirect route based on initial DT model estimation;
- they can easily handle the case of irregularly sampled data;
- they also offer advantages when applied to systems with widely separated modes;
- they are well suited in the case of fast sampling: today's data acquisition equipment reality/

5.2 Wide range of applications

- control system design
- system biology (irregularly sampled data)
- robotic and mechatronic systems (wide band systems)
- finance and econometrics (irregularly sampled data)
- environmental systems (physical interpretation of the model)

5.3 Other recent successful applications

- modeling of an industrial distillation column
- modeling of a flexible robotic arm designed for heart-beating tracking [1]
- modeling of pollutant transport in a river [2],...

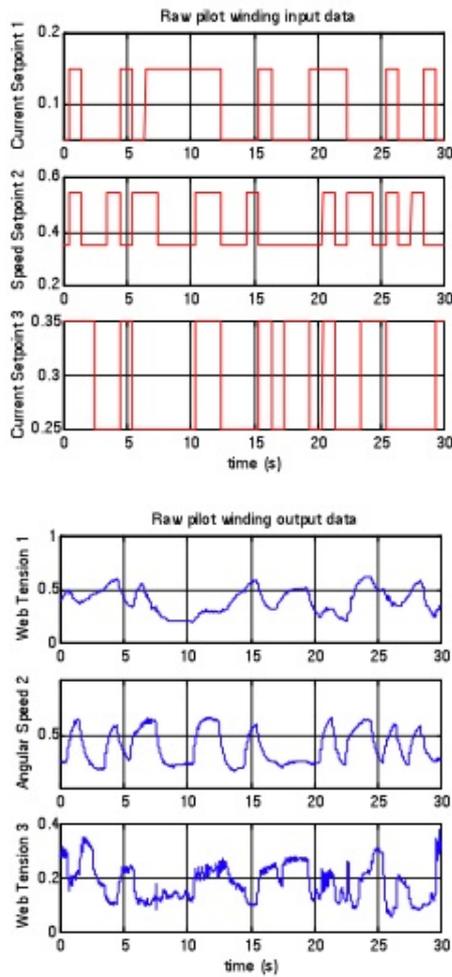


Fig. 5: Winding process data

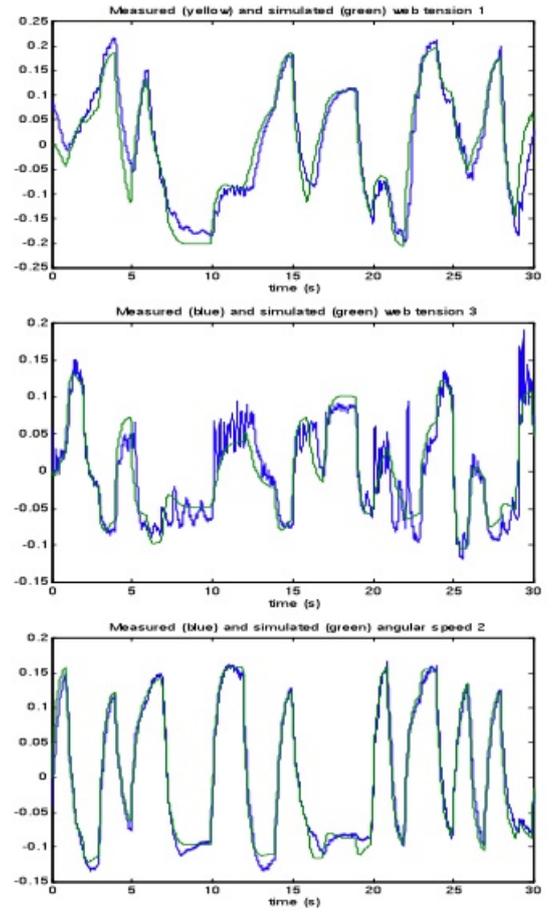


Fig. 6: Cross-validation results

5.4 Comparative performance of DT and CT techniques

DT and CT techniques are used to identify a benchmark, using Monte Carlo simulations. The process to be identify is represented on Figure 8.

This process is defined by

- 2 separated oscillatory modes

$$G_0(p) = \frac{K(1 - Tp)}{\left(\frac{p^2}{\omega_{n,1}^2} + \frac{2\xi_1}{\omega_{n,1}}p + 1\right) \left(\frac{p^2}{\omega_{n,2}^2} + \frac{2\xi_2}{\omega_{n,2}}p + 1\right)} \quad (10)$$

- 1 unstable zero
- simulation conditions : $T_s=10$ ms, $u(t)$: PRBS of max. length, $e(tk)$: white Gaussian noise and SNR=10dB

The results are given on figure 9. This example illustrates some of the well-known difficulties that may appear in DT modelling: sensitivity to the initialisation, numerical issues in the case of fast sampling, a priori knowledge of the system relative degree not easy to accommodate, non inherent data prefiltering, while the direct CT modelling approaches are free from these difficulties.

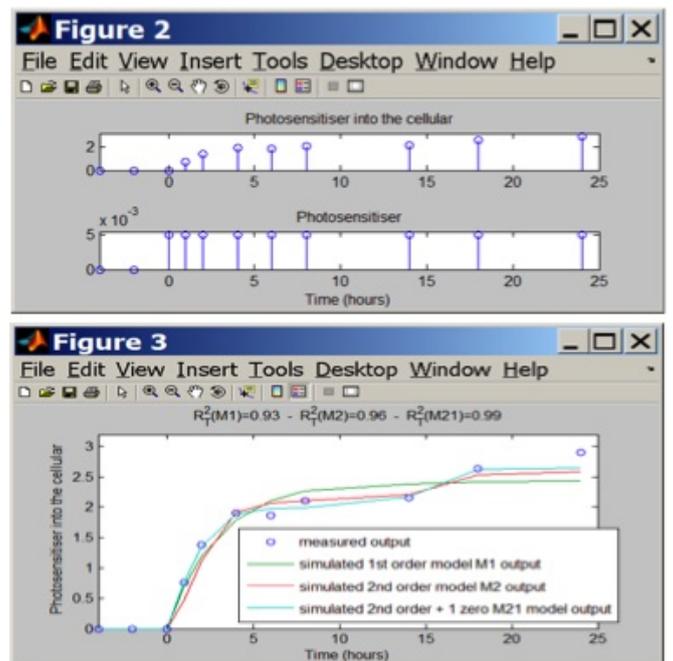


Fig. 7: PDT data

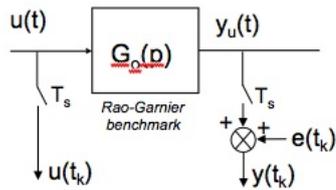


Fig. 8: Process to be identified

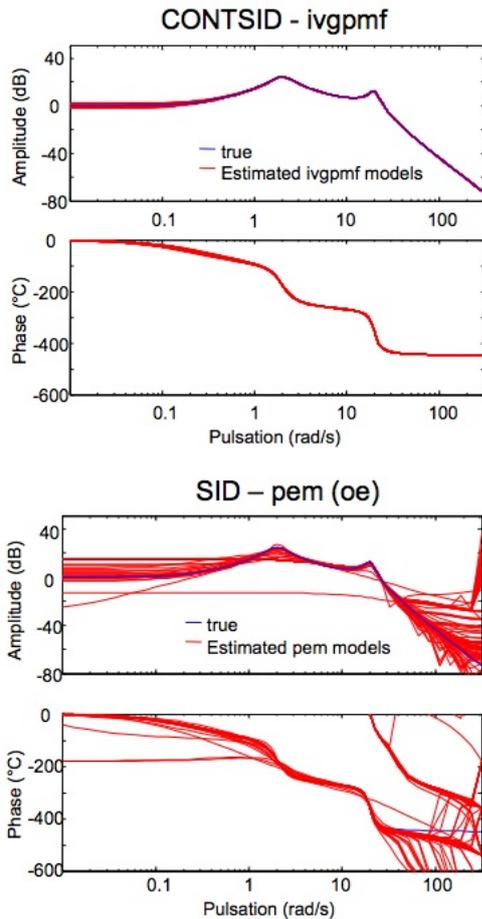


Fig. 9: Benchmark results

6 Conclusion

This paper has outlined the main features of the latest developments for the Matlab CONTSID toolbox. It provides access to most of the time-domain continuous-time model identification techniques that allow for the direct identification of continuous-time models from discrete-time data, is in continual development. Planned new release will include more techniques to solve the non-linear continuous-time model identification problems.

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