Black-box identification of a pilot-scale dryer model: A Support Vector Regression and an Imperialist Competitive Algorithm approach

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Abstract: This report describes system identification by means of the hybrid black-box method. The identification was carried out on the regulation object (a dryer model) representing the pilot-scale processes occurring during air conditioning and drying. The new approach proposed in the paper is the use of the imperialist competitive algorithm (ICA) as a tool for selecting the best parameters for support vector regression (SVR) and for selecting an optimal set of regressors. The advantage of this method is that the selection of an optimal set of regressors and the optimal parameters of SVR for this set is performed automatically, which reduces the time needed for identification. The results of the SVR with the ARX, ARMAX, OE, Box-Jenkins (BJ) and low-order transfer function (TF) models were compared. The research was conducted for two fan speeds, equal to 40% and 60%. The Fit and MSE indicators for the SVR achieved a higher value with respect to those of the ARX, ARMAX, OE, BJ and TF models. This method is sufficiently universal and can be applied to any plant as an efficient alternative method. This report is supported by National Science Centre grant UMO-2015/17/B/NZ7/02937

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set of regressors. The advantage of this method is that the selection an optimal set of regressors as well as the optimal parameters of SVR for this set is performed automatically, which reduces the time needed for identification. Because linear models are very often used in the identification of an industrial process, the results of using SVR and ICA with ARX, ARMAX, OE, BJ (Ljung, 1999) and Tf models, which are available in the Matlab System Identification Toolbox R2010b, were compared. The research was conducted for two fan speeds, equal to 40% and 60%. This method is sufficiently universal and can be applied to any plant.

2. BLACK-BOX IDENTIFICATION

Because SVR was taken as a non-linear network, black-box identification will be described with a focus on non-linear models (Juditsky et al., 1995). Assuming that \( u(t) \) is a discrete input of a non-linear system, and \( y(t) \) is an output, the data set can be defined as:

\[
\mathbf{u} = [u(1), u(2), \ldots, u(t)], \quad \mathbf{y} = [y(1), y(2), \ldots, y(t)]
\]

(1)

where \( u(1), \ldots, u(t), y(1), \ldots, y(t) \) are sequential samples in time.

The idea of black-box identification is to find the connection between past observations, i.e., \( u(t-1), \ldots, u(t-n_u), y(t-1), \ldots, y(t-n_y) \), and the future \( y(t) \). The primary goal is estimating a non-linear function as follows:

\[
y(t) = f\left(\mathbf{u}(t-1), \ldots, \mathbf{u}(t-n_u), y(t-1), \ldots, y(t-n_y), \mathbf{0}\right) + \varepsilon(t)
\]

(2)

Introducing \( \mathbf{x}(t) = [u(t-1), \ldots, u(t-n_u), y(t-1), \ldots, y(t-n_y)] \), can be expressed as follows:

\[
y(t) = f(\mathbf{x}(t), \mathbf{0}) + \varepsilon(t)
\]

(3)

where \( f(\cdot) \) is the unknown basis function, \( \mathbf{x}(t) \) is the regression vector, \( n_u \) is the number of past observation samples of the input, \( n_y \) is the number of past observation samples of the output, \( \mathbf{0} \) is a vector of associated parameters, \( \varepsilon(t) \) is the noise and its value should be as small as possible.

Parameterizing the unknown basis function \( f(\cdot) \) can usually be approximated by a finite dimensional vector \( \mathbf{0} \). The vector of associated parameters \( \mathbf{0} \) can be assessed by means of a fit between the model and the data set:

\[
\sum_{i=1}^{n_u} \left\| y(t) - f\left(\mathbf{u}(t-1), \ldots, \mathbf{u}(t-n_u), y(t-1), \ldots, y(t-n_y), \mathbf{0}\right) \right\|^2 = \left\| \mathbf{y}(t) - \mathbf{F}(\mathbf{u}(t), \mathbf{0}) \right\|^2
\]

(4)

The elements of vector \( \mathbf{x}(t) \) are called regressors and, depending on the choice of the vector of regressors, we can build a variety of models: NFIR, NARX, NARMAX, NOE, NBJ (Sjöberg et al., 1995). The problem of identification for each model comes down to finding the number of regressors, i.e., the number of past observation samples and the non-linear function \( f(\cdot) \), to obtain the model with the best fit to the object. Finding a suitable number of regressors is very important. An excessive number of regressors may lead to the creation of a very complex model and variable duplication. A large number of irrelevant regressors can cause overfitting, which results in a poor generalizability of the model.

3. SUPPORT VECTOR REGRESSION (SVR) IN PROBLEM IDENTIFICATION

Support vector machines (SVMs) that address modeling and prediction are called support vector regressions (SVRs) (Smola and Scholkopf, 1998). Because support vector machines (SVMs) and support vector regression (SVR) are often presented in the literature (Salat and Salat, 2013; Salat and Osowski, 2011; Wen et al., 2006), only a basic presentation of SVR in problem identification was presented. To present the algorithm of SVR, it must first be introduced on the projection function \( F \) from the regressors’ space \( \mathcal{R} \) to a hypothetical feature space \( \mathcal{N} \). Assume that the training set is as follows:

\[
(\mathbf{x}_1, y_1), \ldots, (\mathbf{x}_n, y_n) \in \mathcal{R}^N \times \mathcal{R}
\]

(5)

where \( \mathbf{x}_n \) is the input vector composed of the regressors for the NARX model, and \( y_n \) is output.

By defining the \( \varepsilon \)-insensitive loss function as

\[
|y - f(\mathbf{x})|_\varepsilon = \max\{0, |y - f(\mathbf{x})| - \varepsilon\}
\]

(6)

the procedure can be treated as quadratic programming (QP), and the estimation function can be expressed in the "standard" SVR as

\[
f(x) = \langle w, \mathbf{x} \rangle + b, \quad \mathbf{x}, b \in \mathcal{R}
\]

(7)

where \( w \) is the weight vector and \( b \) is the bias.

Then, \( f(x) \) can be determined from the minimization problem as follows:

\[
\min_{w, b, \xi_n^\pm} \frac{1}{2} \|w\|^2 + C \sum_{i=1}^{n_u} \xi_i + \frac{1}{2} \sum_{i=1}^{n_u} \xi_i^* \quad \text{subject to:}
\]

\[
y_i - \langle w, \mathbf{x}_i \rangle - b \leq \varepsilon + \xi_i^\pm, \quad \mathbf{x}_i \cdot \mathbf{F}(\mathbf{x}_i) - y_i \leq \varepsilon + \xi_i^*, \quad \xi_i^\pm, \xi_i^* \geq 0
\]

(8)

where \( n \) is the number of training data pairs.

Introducing slack variables \( \xi_n^\pm, \xi_n^* \) into (8), an optimization problem can be formulated as follows:

\[
\min_{w, \xi_n^\pm, \xi_n^*} \frac{1}{2} \|w\|^2 + C \sum_{i=1}^{n_u} \xi_i + \frac{1}{2} \sum_{i=1}^{n_u} \xi_i^* \quad \text{subject to:}
\]

\[
y_i - \langle w, \mathbf{x}_i \rangle - b \leq \varepsilon + \xi_i^\pm, \quad \mathbf{x}_i \cdot \mathbf{F}(\mathbf{x}_i) - y_i \leq \varepsilon + \xi_i^*, \quad \xi_i^\pm, \xi_i^* \geq 0
\]

(9)

which is subject to:

\[
k(\mathbf{x}_i, \mathbf{x}_j) = F^T(\mathbf{x}_i) F(\mathbf{x}_j)
\]

(11)

that is defined in accordance with Mercer’s theorem (Vapnik and Chervonenkis, 1974). The formulation of the dual problem is equivalent to finding an expression as follows:

\[
\min_{\alpha, \alpha^*} \frac{1}{2} (\alpha - \alpha^*)^T Q(\alpha - \alpha^*) + \varepsilon \sum_{i=1}^{n_u} \alpha_i + \sum_{i=1}^{n_u} \alpha_i^* \quad \text{subject to:}
\]

\[
\alpha_i, \alpha_i^* \geq 0
\]

(12)
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