Model-Free Predictive Control for Nonlinear Systems

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Abstract

Model-free predictive control directly computes the control input from massive input/output datasets and does not use a mathematical model. In contrast, conventional model predictive control relies on mathematical models. Although the underlying principle of model-free predictive control utilizes linear regression vectors comprising input/output data, it can also be applied to control nonlinear systems. In this study, the linear regression vectors are extended to polynomial regression vectors, improving the control performance. Using numerical simulations, we demonstrate the effectiveness of this approach.

Summary

Over the last four decades Model Predictive Control (MPC) gives a great impact to control engineering. MPC is a control idea of models that find control method by on-line or off-line for optimizing the objective functions as shown in Fig.1. However, most of task have depended on linear systems in current, when a nonlinear system is involved, not only do we need to obtain perfect model for the systems, but also increase the computational burden.

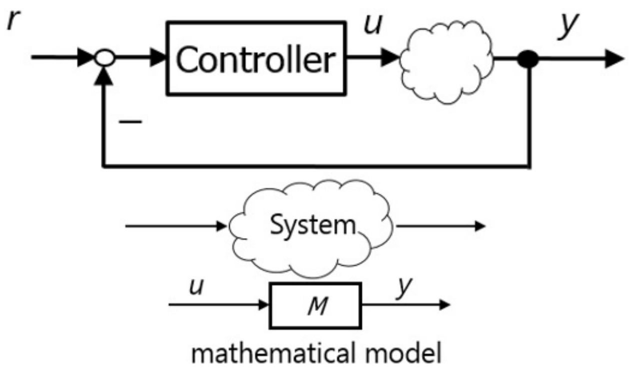


Figure 1: The simple structure of model predictive control

In order to solve these problems, a model-free predictive control method was proposed as data-driven control which does not need any mathematical models and computational burden also can be significantly reduced. Contrast to standard MPC utilizing mathematical models, the model-free predictive control method uses stored input and output datasets to compute an optimal control input from the neighbors of the current situation. The model-free predictive control method uses a local linear model which is constantly updated based on the so-called Just-In-Time modeling that utilizing both online measured input/output data and recorded past data to adaptively obtain a local model. This method is also referred to as model on-demand, lazy learning, or instance based learning. The technique is applied to prediction of production processes in the steel industry, PID parameter tuning, and soft sensors in industrial chemical processes.

In this thesis, we introduce a model-free predictive control method for linear and nonlinear system based on polynomial regressors that according to Volterra series. It is not only a class of polynomial representation of nonlinear system, but also natural extension of the classical linear system representation. Volterra series includes a series of nonlinear terms that contain product of increasing order Volterra kernel and input/output signal space, and the Volterra kernel and input/output signal space are not interdependent. Therefore, input/output signal space of polynomial regression can be used individually. The polynomial regression is a form that can be extended by the linear regression; it describe one relationship between the independent variable and dependent variable, which was modeled as a pth degree polynomial. Therefore, polynomial regression vectors can fit a nonlinear relationship between the independent variable vectors and dependent variable vectors that can describe nonlinear phenomena.

Model-free predictive control that directly computes the control input from massive input/output datasets and does not use a mathematical model as shown in Fig.2. In contrast, conventional model predictive control relies on mathematical models. Although the underlying principle of model-free predictive control utilizes linear regression vectors comprising input/output data, it can also be applied to control nonlinear systems.

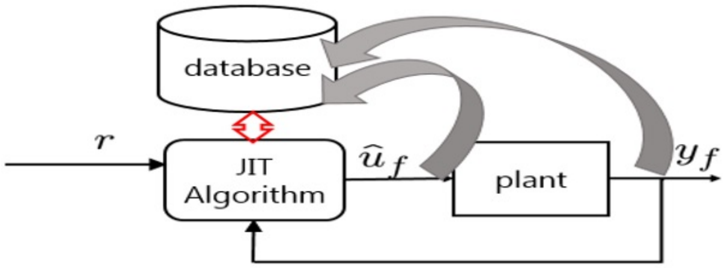


Figure 2: General Overview of Data Driven method

In this study, the linear regression vectors are extended to polynomial regression vectors that contain the control input and measurement output. It has recently been shown that the control offered by model-free predictive control can be improved. There is an indicator for us to discuss the conclusion that is an error with a reference trajectory r ($r = -1, 0,$ and 1). we used the nonlinear system to verify model-free predictive control method based on the order of polynomial regressors. We generated a dataset containing samples ($t = 500$) of control input $u(t)$ and measurement output $y(t)$ with a uniform distribution, as shown in Figs. 3 and 4. The control input $u(t)$ was generated and applied to nonlinear system to obtain the first dataset as shown in Fig. 3. The second dataset was generated to use PI control as shown in Fig. 4. In the second dataset more y values were presented close to reference r than in the first dataset, as can be observed in the histograms in Fig. 3 and 4. we compared the performance of the model-free predictive control when using two datasets. In the simulation results shown in Fig. 5 and 6, the broken line represents the reference r. It can be observed that the tracking error $e = r - y$ in Fig. 6 is smaller than that in Fig. 5. Therefore, we know that datasets containing many y around r are required to reduce the tracking error.

In addition, an appropriate combination of parameters effect the control performance, using numerical simulations, we demonstrate the effectiveness of this approach, and discuss the appropriate combination of parameters. At last we extend these findings to multi-input multi-output nonlinear systems investigate the effectiveness of the approach through application of a wastewater treatment process.

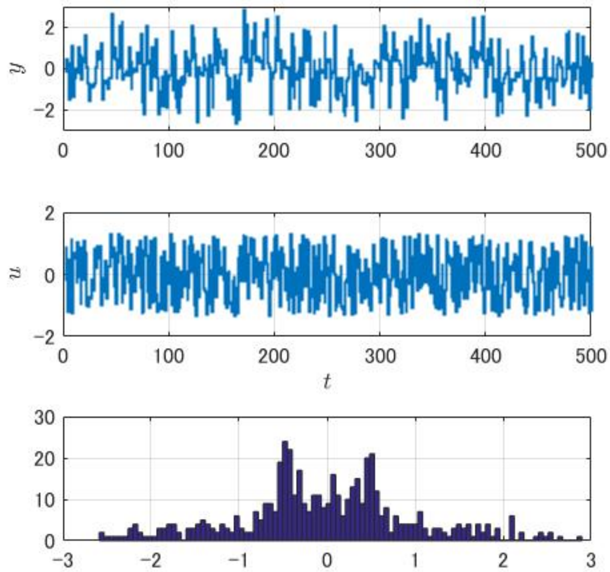


Figure 3: Stored datasets for model-free predictive control of nonlinear system to obtain control results shown in Fig. 5. Histogram of values of output y in the dataset used to obtain control results in Fig. 5.

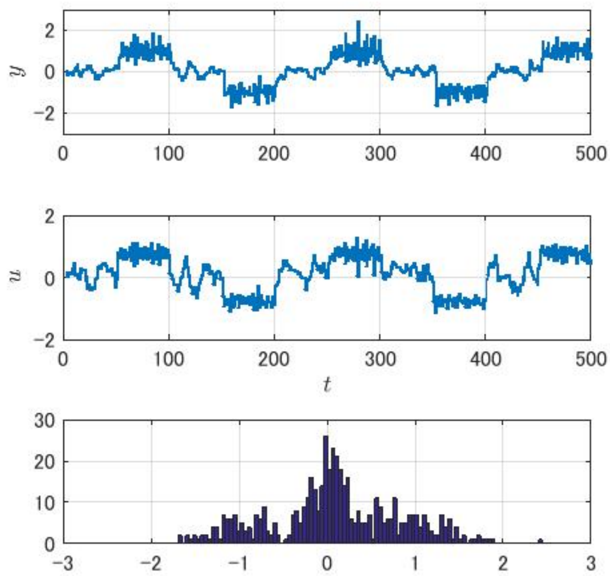
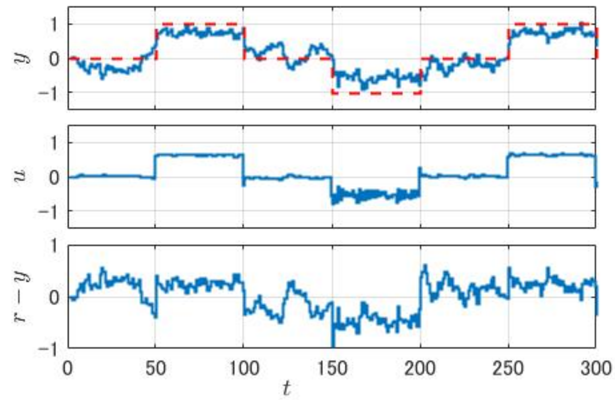
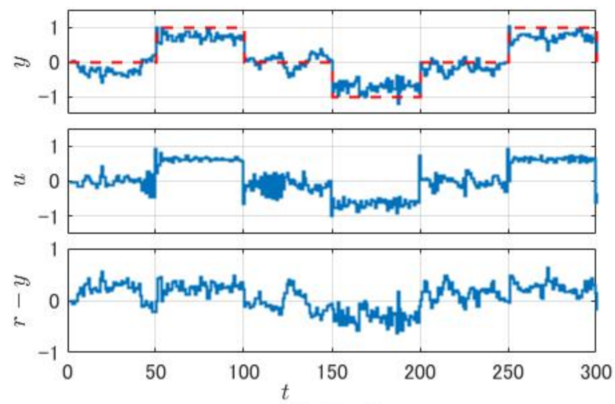


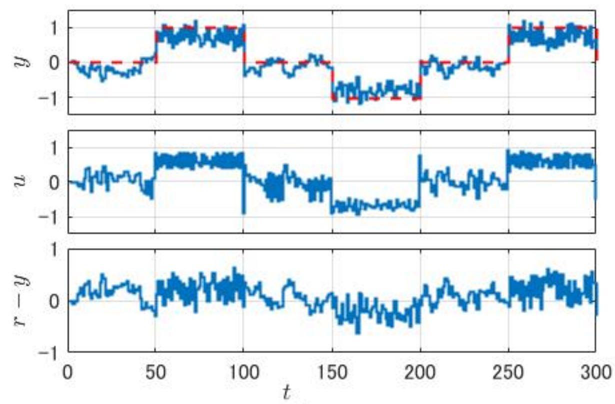
Figure 4: Stored datasets for model-free predictive control of nonlinear system to obtain control results in Fig. 6. Histogram of values of output y in the dataset used to obtain control results in Fig. 6.



(a) $P = 1$

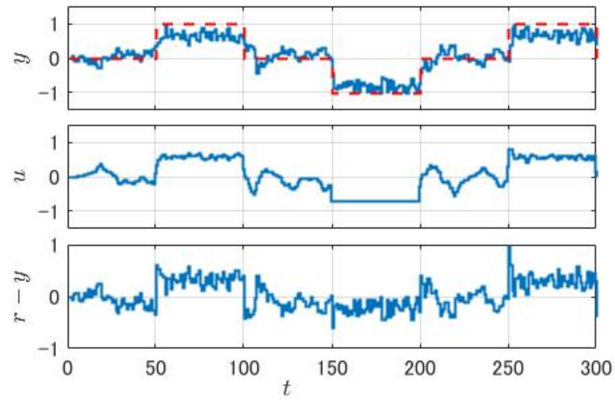


(b) $P = 2$

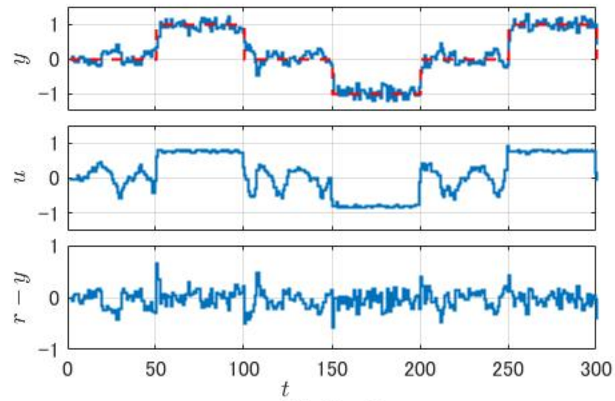


(c) $P = 3$

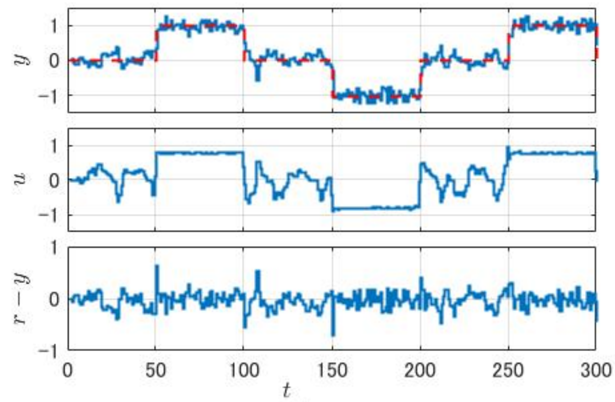
Figure 5: Simulation results of model-free predictive control for the nonlinear system based on the datasets in Fig. 3. (a) Order $P = 1$, (b) order $P = 2$, and (c) order $P = 3$.



(a) $P = 1$



(b) $P = 2$



(c) $P = 3$

Figure 6: Simulation results of model-free predictive control for nonlinear system based on the datasets in Fig. 4. (a) Order $P = 1$, (b) order $P = 2$, and (c) order $P = 3$.

平成２９年　2月　6日

学位論文審査報告書（甲）

1．学位論文題目（外国語の場合は和訳を付けること。）

Model-Free Predictive Control for Nonlinear Systems

（非線形システムのモデルフリー予測制御）

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3．審査結果の要旨（600～650字）

当該学位論文に関し，平成２９年２月６日に第１回学位論文審査委員会を開催した．同日に口頭発表を実施し，その後に第２回審査委員会を開催した．慎重審議の結果，以下の通り判定した．なお口頭発表における質疑を最終試験に代えるものとした．

本論文は，制御対象の数式モデルを用いる代わりに制御対象の観測値を直接予測制御に利用する制御方式に関する研究をまとめたものである．本論文の研究対象であるモデルフリー予測制御は，制御対象の入出力観測データを事前に大量に蓄えておき，制御時にその中から予測に必要となるデータのみを抽出して，最適な制御入力の計算を行う手法である．

本研究は，制御対象が非線形性を有する場合にモデルフリー予測制御の制御性能を改善るために，多項式回帰を利用する方法を提案し，その有効性を示すものである．入出力観測データを多項式回帰に相当する高次の項まで利用する原理は，これまでの線形回帰に基づく原理の拡張となっている．提案法の有効性は，非線形性が特徴的な下水処理プロセスの制御システムへの適用において数値シミュレーションで確認されている．制御対象が非線形要素を含む場合は予測制御に利用できる正確な数式モデルの構築は困難であり，そのような制御対象の数式モデルを必要としない予測制御は産業応用でも重要である．

以上の研究成果は，データを活用する予測制御の研究に新しい知見を与えるだけでなく産業応用での貢献も大きい．従って，本論文は博士（工学）に値すると判定した．

4．審査結果　　(1) 判　　定（いずれかに○印）　○合　格　・　不合格

(2) 授与学位　　博　士（　工学　　）