Neural Networks in Model Predictive Control

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Abstract. This work is concerned with Model Predictive Control (MPC) algorithms in which neural models are used on-line. Model structure selection, training and stability issues are thoroughly discussed. Computationally efficient algorithms are recommended which use on-line linearisation of the neural model and need solving on-line quadratic optimisation tasks. It is demonstrated that they give very good results, comparable to those obtained when nonlinear optimisation is used on-line in MPC. In order to illustrate the effectiveness of discussed approaches, a chemical process is considered. The development of appropriate models for MPC is discussed, the control accuracy and the computational complexity of recommended MPC are shown.

Keywords: Process control, Model Predictive Control, neural networks, model identification, optimisation, quadratic programming, linearisation.

1 Introduction

Model Predictive Control (MPC) is recognised as the only advanced control technique which has been very successful in practice [29,43,44,47]. It is mainly because MPC algorithms can take into account constraints imposed on both process inputs (manipulated variables) and outputs (controlled variables), which usually decide on quality, economic efficiency and safety. Moreover, MPC techniques are very efficient in multivariable process control (i.e. for processes with many inputs and outputs) and for processes with difficult dynamic properties, e.g. with significant time-delays. Different versions of MPC algorithms are nowadays used in numerous fields, not only in chemical, food and motor industries, but also in medicine and aerospace [13].

MPC techniques based on easy to obtain linear models are frequently used in practice [43]. In many cases their control accuracy is sufficient, much better than that of the classical PID approach. Nevertheless, in the last two decades numerous MPC algorithms based on nonlinear models have been developed and have gained in popularity [12,35,43,47,48]. When applied to significantly nonlinear processes, they significantly improve the control accuracy in comparison with MPC approaches which use linear models.

In MPC a dynamic model of the process is used to predict its behaviour over some time horizon and to determine the optimal future control policy. Hence, the
choice of the model structure which is used in nonlinear MPC is extremely important. Main measures of model utility are: approximation accuracy, suitability for control and easiness of development [39]. Fundamental (first-principle) models [19,30], although potentially very precise, are usually not suitable for on-line control. Such models are comprised of systems of nonlinear differential and algebraic equations which have to be solved on-line in MPC at each sampling instant. It is usually computationally demanding as fundamental models can be very complex and may lead to numerical problems (e.g., stiffness, ill-conditioning). Moreover, in many cases the development and validation of fundamental models is difficult, it needs technological knowledge.

This work presents MPC algorithms based on neural models [11]. In spite of the fact that a number of different nonlinear black-box model types are available (e.g., polynomial models, fuzzy models, Volterra series models [39]), neural networks have some unique features thanks to which they can be very efficiently used on-line in MPC. More specifically, neural networks are universal approximators [13], have relatively a small number of parameters and a simple structure. Moreover, they directly describe relations between inputs and outputs of the process, which means that during on-line control it is not necessary to solve complicated systems of nonlinear differential equations at each sampling instant as it is necessary when fundamental models are used. In consequence, neural models can be effectively used in MPC as models of technological processes. In particular, thanks to a simple, regular structure of neural models, the implementation of described algorithms is relatively easy. Neural models are trained using recorded data sets, no technological knowledge is necessary.

Although the literature concerned with MPC algorithms based on neural models is quite rich [1,2,3,4,5,6,7,8,9,10,12,14,16,18,20,21,22,23,24,25,26,27,28,33,35,37,40,41,42,47,48,49,50,51,52], there are a few issues worth exploring. First of all, the way the nonlinear model is used on-line in MPC is crucial in light of the computational complexity and reliability of the whole control system. In theory, neural models can be used directly without any simplifications but it means that the optimal control policy at each sampling instant must be calculated from a nonlinear optimisation problem. It is not only computationally very demanding but also the optimisation routine is likely to terminate at shallow local minima. In order to reduce the computational burden and increase reliability, in this work suboptimal approaches are recommended. The nonlinear neural model is linearised on-line and next the obtained local approximation is used in MPC algorithms [10,20,21,22,23,24,25,26,27,28,37,47,48]. Thanks to using for control a local linearisation of the original neural model, the necessity of on-line nonlinear optimisation is avoided, it is replaced by an easy to solve quadratic programming problem. It is demonstrated in this work that suboptimal MPC algorithms with on-line linearisation are very precise, the control accuracy is comparable to that obtained when a nonlinear optimisation routine is used on-line at each sampling instant.

The second important issue discussed in this work is the choice of the model structure and training. It is emphasised that MPC algorithms are very