The State-of-the-art of Model Predictive Control in Recent Years

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Abstract. Model predictive control is a control algorithm based on model and online application optimization performance. In the past 40 years, the feedback control strategy has been widely studied. However, with the rapid development of the economy, the requirements for online optimization and constrained performance have been improved, and the current model predictive control theory can not meet the demand any more. This paper first briefly describes the current situation of model prediction, industrial development, and application areas, and then analyzes the limitations of theory and technology at the current stage, then proposes the significance of the study of predictive control of large-scale systems, fast dynamic systems, and nonlinear systems for the development of model predictions.

1. Introduction
Model predictive control (MPC) has mainly focused on online optimization since it is studied. After a long period of development, it now has a rich theoretical and practical foundation in the academic community [1]. The view "process control: theory and benefits" pointed in the 12th IFAC World Conference on model predictions can be simplified into the following features:

- The main feature of model predictive control is online constraint optimization.
- Model predictive control is mainly used in industrial process control.
- There is a disconnect between the practical application of model predictive control and theory

In recent years, through reading a large number of documents, it can be understood that the field of using model predictive control to solve constrained optimization problems is being expanding, such as urban life, medical care, power grids, energy, development, aerospace and so on. For example, microgrid operation management [2], the strategy of drinking water network management [3], Type I diabetes insulin delivery control [4], System for building heating [5], vehicle traffic simulation autopilot [6], spacecraft intersection [7], etc. This is in contrast to the model prediction that mainly application in industrial process in the early stage. This directly shows people's increasing demand for model forecasting technology and the expectation of rapid development. This paper analyzes the current domestic and foreign predictive control technologies, points out the problems, and puts forward several opinions on the development prospects of model predictive control.

2. The Model Predictive Control Theory and Research Status

2.1. The Model Predictive Control Theory
In recent years, traditional monotonous predictive control algorithms can't meet increasingly complex industrial process requirements any longer. It is continuously combining with other algorithms to develop more advanced and accurate predictive control strategies. For example, combine engineering economics with predictive control to economic nonlinear model predictive control [8], composite neural network predictive optimal anti-interference control algorithm combined with neural network [9], model predictive control algorithm based on T-S fuzzy modeling [10], model predictive control based on reinforcement learning [11], etc.

Since the development of predictive control, it dealt with the complex constraints mainly through optimization. A large number of papers point that the advantage of predictive control being widely used and developed is that its algorithm has two important features. The first is the capability of display the constraint processing [12], the second is that it easily extend the algorithm to a multiple-input multiple-output system. At present, the successful application of thousands of industrial equipment to this technology shows that predictive control can be used as a mature control algorithm and is recognized by industrial control. In China, predictive control has been incorporated into national key scientific research projects, and universities and companies have successively developed predictive control software with independent intellectual property rights.

2.2. The Research Status

With the development of science and technology and the increased industrial demand, people are more clearly aware of the deficiencies both predictive control theory and industrial applications that mentioned above, thus promoted in-depth research in this field. According to incomplete statistics, we counted the number of papers published in several well-known journals in the control field. The statistics are shown in Figure 1.

![Figure 1. The statistics of related papers for Model Predictive Control](image)

According to the comparison between the number of articles written in the past decade and the number of articles written in the past two decades, we can see that there has been a large increase in research on Model Predictive Control in recent years. At the same time, in China, the scope of industrial applications for predictive control is also expanding, from the distillation, petrochemical, and other industries to energy saving [13], irrigation [14], power generation [15], medical [16], shipping [17] and urban transportation [18], various new algorithms and control strategies were
gradually proposed. The research conducted at home and abroad at this stage can be mainly divided into the following aspects:

2.2.1 Non-linear Predictive Control. a) Linearized nonlinear predictive control: linearized the nonlinear model firstly, then rolling optimizations for linearized models, while a nonlinear model is used in the model design and feedback part.

b) Non-linear predictive control of hybrid systems: This type of system is well suited for describing discrete dynamic processes with logical switching. By adding logic variables, the segmented system with the logic switching characteristics is converted into a hybrid logic system, and then the optimal control is designed.

c) Multi-model nonlinear predictive control: This type of system introduces multi-model methods into predictive control and uses several different linear models to approximate nonlinearity.

2.2.2 Random Predictive Control Model. The stochastic system uses probabilistic uncertainty to describe the system, but the uncertainty meets certain probability statistics. According to the nature of the research object, it can be divided into two categories: random uncertainty model and random disturbance model. For the stochastic uncertain model with normal distribution, Tube technology can be used for further research [19], random perturbation model can refer to Wang [20] for affine perturbation feedback.

2.2.3 Predictive Control Applied to More Fields. a) New prediction algorithm combined with other control algorithms.

In recent years, predictive control has broken the original monotony of the algorithm research model, and began to combine with other algorithms to develop a class of advanced predictive control strategies. The mainly aspects is as shown in table 1:

| Control Strategy                      | Application Examples                                                                 |
|--------------------------------------|--------------------------------------------------------------------------------------|
| PID Predictive Control               | Using predictive function control optimization and designing of a new PID controller for chamber pressure in a coke furnace [21] |
| Fuzzy Predictive Control            | Using the Fuzzy Predictive Control Strategy to control the heating and cooling of the buildings [22] |
| Adaptive Predictive Control         | Using the Adaptive Model Predictive Control to achieve quadrotor altitude efficiently [23] |
| Neural Network Predictive Control   | Using the Neural Network Predictive Control structure for control of thermal processes to save energy [24] |

b) Industrial Application Extensions

In recent years, industrial applications for predictive control have focused more on the integration of economic indicators. On one hand, economic indicators are directly added to the dynamic control of economic predictive control. On the other hand, there are many changes and uncertainties in the production process. As a result, real-time optimization technologies are increasingly used and replacing traditional ones gradually. At the same time, in the face of large-scale and complex industrial production processes, how to implement real-time optimization to achieve global optimization effectively is still an important issue.
3. Problems With Model Predictive At This Stage

Although predictive control has been successfully applied both at home and abroad, it still has the following limitations to effectively solve the complex constrained optimization problems

3.1. From the algorithm point of view
At this stage, the predictive control algorithm is mainly adapted to work in environments with high-performance computers or slow dynamic processes, it limits its broader development space and applications in a large extent. According to the statistics of Qin in the literature [14], the trend can be reflected as follows: Model prediction technology is still only scale application in industrial processes. The limitations of fast dynamic systems such as aeronautics and manufacturing are mainly due to the requirements for high-performance computer equipment. It is difficult for ordinary equipment to perform accurate real-time calculations in small sampling cycles, so it has not been possible to use a large number of applications in these fields.

3.2. From the perspective of the application object: mainly limited to linear or quasi-linear process
The main reason for the limitation is that nonlinear modeling of industrial processes is generally difficult to find precise models, and there is a lack of effective algorithms for nonlinear constraint optimization. At this stage, nonlinear predictive control has become a research hotspot, but industrial practice applications are still in the initial stage.

3.3. A Large number of online computing requirements, it is difficult to meet the application needs
The main research of predictive control is to guarantee the stability and robustness of the closed-loop system in rolling optimization. Most of the prediction algorithms proposed for specific problems are theoretically guaranteed performance, and do not pay attention to the cost of practicing online applications. In recent years, this type of problem has received more attention, but due to the large amount of online calculations, a great deal of attention in the application field can not be obtained.

Due to the brief description of the application of the prediction field and the theoretical analysis, although the application in the industrial process is very successful and the theoretical basis system is also very complete, there is a problem of disconnection between theory and practice, and it can not meet the needs of economic and social development.

4. Model Predictive Outlook

From a large number of predictive control papers, it can be seen that although the industrial development and application of predictive control is relatively successful, the theoretical research of predictive control is relatively complete, however, there is a great degree of disconnection between them, which cannot meet the needs of current social development. Therefore, the research of predictive control theory and efficient algorithms is imminent, gradually reduce the disconnect between theory and practice. Taking this as a goal, we can study from several different aspects, such as large-scale systems, rapid systems, and nonlinear systems, starting from the limitations of existing predictive control technologies, conducting theoretical and algorithmic research, and applying pilot projects in combination with typical cases, improve the practicality and scientific of predictive control algorithms.

4.1. Large-scale System
For large systems with distributed features such as urban traffic and sewage discharge, the existing industrial predictive control algorithms can not be applied directly at this stage. It is necessary to study the convergence, global stability and disturbance robustness of the online information interaction iteration of the predictive control algorithm under different control structures. So far, the development of practical and effective predictive control strategies remains a challenge.

4.2. Fast dynamic system
Equations From the development of predictive control, the industrial process of slow dynamic systems has been successfully applied. However, in the field of fast dynamic systems such as aerospace, electromechanical, etc. It is considered unsuitable for predictive control because the industrial process prediction algorithm requires a large number of iterations to solve the constraint optimization problem online. At present, it is necessary to study algorithms that can guarantee the optimization of the constraints and satisfy the real-time requirements.

4.3. Nonlinear systems
The predictive control of nonlinear systems is not mature either from theoretical research or industrial process practice. Although the in-depth development of predictive control theory has brought new directions to nonlinear systems, it still has no mature conditions for practical application. The problem of nonlinear systems is mainly to reduce the amount of online calculations and nonlinear processing.

5. Conclusion
The core of predictive control theory is online constraint optimization. Confronted with the higher demand for processing optimization in the development of various fields, predictive control also faces more challenges. The study of predictive control should be aimed at reducing the direction of disconnection between theory and practice, which not only has theoretical support but also meet real-time, stability, and rapidity requirements for each application area. This is not only the goal of the relentless pursuit of control theory research, but also the research direction for the future development of predictive control.

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