Journal of Process Control 21 (2011) 738–745

Contents lists available at ScienceDirect

Journal of Process Control

journal homepage: www.elsevier.com/locate/jprocont

Multiple shooting for distributed systems with applications in hydro electricity production

C. Savorgnan [a,*], C. Romani [b], A. Kozma [a], M. Diehl [a]

[a] Electrical Engineering Department (ESAT-SCD) and Optimization in Engineering Center (OPTEC), K.U. Leuven, Kasteelpark Arenberg 10, B-3001 Leuven, Belgium
[b] Dipartimento di Elettronica e Informazione, Politecnico di Milano, Via Ponzio 34/5, 20133 Milano, Italy

ARTICLE INFO

Article history:
Received 21 July 2010
Received in revised form 28 January 2011
Accepted 28 January 2011
Available online 23 March 2011

Keywords:
Model predictive control
Direct multiple shooting
Large scale systems

ABSTRACT

The aim of this paper is to introduce a new method for the solution of optimal control problems for which the system is composed by many subsystems whose dynamics are coupled through input–ouput connections. The proposed approach can be regarded as a generalization of the direct multiple shooting method and exploits the structure of the problem to achieve a highly parallelizable algorithm. To demonstrate its effectiveness, the new method is applied to the control of a hydro power plant composed of several connected reaches.

1. Introduction

Manufacturing systems, process plants and networked systems are often composed by several subsystems. The control of these systems can be very challenging and this is the reason why a lot of research has been carried out in this field. Several results had been achieved in the past decades [9,16] and a revived interest can be seen in recent years, in particular in the field of hierarchical and distributed model predictive control [5,14,20,21,23,29] and control of multi agent systems [4,28]. Most of these works assume that the deployment of local controllers is necessary to control this kind of large scale systems. However, the adoption of local controllers which are coordinated to achieve some global properties comes at a price. The computation of an optimal value for the inputs requires a large number of iterations when compared with other methods which compute the inputs in a centralized way.

When the use of local controllers is not imposed by design constraints, a centralized controller can be still a viable alternative. A straight implementation of standard control methods could not be applicable due to computational complexity and poor maintainability. To solve this problem it is necessary to exploit the problem structure to achieve a numerically efficient method [13,30]. When designing a method for large scale systems it is important to keep in mind the architecture of the available computers and the possibility to keep model maintenance local. After decades of increasing clock speeds of the processors, last years have shown a new trend where the clock speeds are slowly changing but the number of processors available on a single workstation is increasing rapidly. This fact increases the importance to develop parallelizable algorithms.

An effective method to solve nonlinear optimal control problems with continuous time dynamics is the direct multiple shooting method [3]. This method divides the control horizon into intervals on which the control inputs are parametrized. A standard nonlinear programming problem is obtained by including in the formulation the value of the states only at the start of each time interval. Integrators are used to take care of the continuous-time dynamics between these points. The optimization problem can then be solved using nonlinear programming methods as sequential quadratic programming (SQP). When applied to multiple shooting, SQP requires the calculation of many derivatives. In practical applications, this constitutes a large amount of the computation time.

Contribution: In this paper we introduce an extension of multiple shooting for optimal control problems which considers several subsystems coupled through input–output connections. The structure is exploited to distribute the computational load required by the integration of the subsystems. This is achieved by representing the coupling variables as a linear combination of basis functions. The new method is called multiple shooting for distributed systems (MSD) and shows the following advantages:

- The algorithm is highly parallelizable.
- Different integrators can be used for the subsystems – this is a very useful property when dealing with multiphysics systems.

* Corresponding author.
E-mail address: carlo.savorgnan@esat.kuleuven.be (C. Savorgnan).

0959-1524/$ – see front matter
doi:10.1016/j.jprocont.2011.01.011