CS 267: Applications of Parallel Computers
Assignment 0

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1 Biography

I am a second year graduate student pursuing my PhD in Mechanical Engineering with an emphasis in Controls. My main research interests lie in the realm of Model Predictive Control (MPC), an optimization based control technique. I am particularly interested in Distributed Model Predictive Control (DMPC), which seeks to form algorithms to split up computation of the MPC solution. I have been studying this topic with respect to building Heating, Ventilation, and Air Conditioning (HVAC) systems in order to optimize energy efficiency and minimize utility costs. However, MPC is a general control strategy that can be applied to a variety of systems. In this class, I hope to learn about the capabilities and limitations of parallel computing as well as the methods for general implementation of parallel computing on distributed processors. Overall, I am interested in the potential that parallel computing presents for Model Predictive Control.

2 Application: Distributed Model Predictive Control

Model Predictive Control is one of the most sophisticated control methodologies studied today. In many applications, it surpasses the performance of other control techniques, such as the commonly used Proportional-Integral-Derivative Control (e.g. a comparison in building HVAC systems is shown in [5]). MPC can be used for a variety of systems because it handles multiple inputs and multiple outputs. The general idea of MPC is to formulate an optimization problem that maximizes or minimizes some cost to achieve a control objective (e.g. trajectory tracking) while subject to some constraints (e.g. controller limits). This optimization problem is then resolved periodically in order to utilize feedback. The controller includes a model of the system, allowing it to predict the behavior of the system in order to compensate for future expectation. This is highly advantageous over the purely reactive behavior of PID controllers. For more technical details on Model Predictive Control, see [3].

A drawback of MPC is the large amount of computation it requires to repeatedly solve an optimization problem. Some factors of this complexity include the convexity of the problem as well as the size of the search space. Thus, MPC has been most commonly used in the process industry, and is usually studied for either slow-moving systems or low complexity models.

Therefore, there exists interest in parallelizing the computation of such a controller. In some cases, as in buildings, it particularly makes sense to distribute computations amongst multiple processors because they already exist in a distributed network structure throughout the rooms of the building. In other cases, any parallelization to help speed up the solution time for an optimization problem would enable MPC to be used for faster systems and more complex models.

In the following subsections, I write about two approaches to distributing MPC computation, and I write about my current research and my intentions with regard to parallel computing.

2.1 Parallel Quadratic Programming for MPC

One parallelization performed for MPC is the work done parallelizing the computation of the solution to quadratic program formulations of MPC [1]. This paper formulates an iterative procedure that splits up the problem into N subproblems, where N is either the number of inputs or the number of dual variables to be determined, depending on the problem.

The work implements the algorithm on a single processor using multiple threads on a 2.4 GHz Intel CoreTM2 CPU machine. For multiple problem formulations, the parallel algorithm shows considerable speedup (up to 60x) compared to the sequential solver provided by Matlab called quadprog. This speed-up is promising, but it is unclear how this might scale with multiple processors. Also, the solution only applies to the class of problems that can be formulated as a quadratic program.

2.2 Distributed Model Predictive Control: Local MPC with Network Coordination

The work presented by Camponogara et al [2] is another approach to distributing model predictive control where there is an emphasis on decreasing communication. Instead of splitting up the computation of a single MPC problem that defines the control of a networked system as a whole, Camponogara formulates local MPC problems for nodes of the network that aim to converge to this global MPC problem. The idea of local MPC is that each node attempts to regulate only its own states and variables with limited interactions with neighboring nodes. The first approach in the paper uses iterative coordination amongst nodes to converge to the global MPC solution, and the second approach studies the stability of the solution when only one message passing between neighbors is allowed each time the optimization problem is resolved.

The key difference between this paper and the parallel quadratic programming paper is that this work formulates one MPC problem for each node of the network, whereas the other paper formulates only one MPC problem for the system as a whole and splits up the computation of that problem. This paper is interesting because it addresses the problems of synchronization and communication over a network. Only simulations of the proposed concept were provided, so it is difficult to know the speed of actual networked hardware.

2.3 My Future Work

In the paper that I have submitted to the 2013 European Control Conference [4], I formulated a distributed approach to solving a centralized MPC problem, with application to building HVAC systems. The method developed applies to a class of quadratic programs with a hierarchical network structure. Of particular note, the solution requires minimal iterations of communication between neighboring nodes, with a maximum of two iterations each time the optimization problem is solved.

The next step for this work is to implement this algorithm using multi-processor computing. This particular problem is interesting in application to the building HVAC system because embedded platforms are already set up in buildings with the same hierarchical network structure that was examined in my paper. I am particularly interested in how this algorithm compares to current heuristic-based algorithms that are currently implemented on building HVAC systems.

References

[1] M. Brand, V. Shilpiekandula, and S.A. Bortoff. A parallel quadratic programming algorithm for model predictive control. *International Federation of Automatic Control (IFAC)*, 18(1), August 2011.

[2] E. Camponogara, D. Jia, B.H. Krogh, and S. Talukdar. Distributed model predictive control. *Control Systems, IEEE*, 22(1):44 –52, feb 2002.

[3] F.Borrelli, A. Bemporad, and M. Morari. Predictive control. `http://www.me.berkeley.edu/~frborrel/pub.php`.

[4] S. Koehler and F. Borrelli. Building temperature distributed control via explicit mpc and ”trim and respond” methods. Technical report, 2013. `http://www.mpc.berkeley.edu/people/sarah-koehler`.

[5] Yudong Ma, F. Borrelli, B. Hencey, B. Coffey, S. Bengea, and P. Haves. Model predictive control for the operation of building cooling systems. *Control Systems Technology, IEEE Transactions on*, 20(3):796 –803, may 2012.