**432m A General Purpose Processor Implementation of Mpc for Insulin Delivery Devices**

*Leonidas G. Bleris and Mayuresh V. Kothare*

The realization of Active Implantable Medical Devices (AIMDs) is the next logical step to recent advances in mechanical engineering, electrical engineering, computer science and medicine. Fusion of ideas from the above fields, coupled with the need to deal with chronic diseases has resulted in a series of innovative applications. Most of these applications fall into the category of passive implantable medical devices (i.e. artificial joints, stents, valves), nevertheless the future belongs to those devices that can sense, think (carry out advanced algorithms) and act. The development of novel medical sensors, and drug delivery methods have introduced multiple benefits to medical devices. These include safety, efficacy, robustness, and patient compliance. For example, advances over the past few years in microfabrication technologies have allowed researchers to create microneedles [1] that painlessly cross the uppermost layer of the skin to effectively and efficiently deliver drugs to depths as shallow as 1mm. Their sizes range from one millimeter to one micron in diameter, being too minute to stimulate nerve endings and cause pain. Additionally, non-invasive needle-free injection devices are under research and development [2]. The key to needle-free injection is to release the drug in liquid form at the proper (extremely high) velocity so that it diffuses through the skin.

Looking at the future, the end target is to develop small and compact drug delivery devices that require minimal power and can maximize the therapeutic results of a drug. For the former, integrated batteries can be used in order to provide enough power to an implant for five to eight years of life, without causing side effects. The latter can be accomplished by minimizing selected cost functions in an optimization procedure (the actual cost function will depend upon the particular application and the control objectives). Classic control algorithms can be used for drug-delivering medical devices. These algorithms can be implemented easily on chip, can be robust, and have relatively low energy consumption. Nevertheless, the human organism is one of the most complex dynamical systems. Therefore the need for advanced control schemes becomes essential under the existence of nonlinearities, constraints, patient variability and delays. Given the increased understanding of physiological, pharmacokinetic and pharmacodynamic models we can apply model based control schemes [3]. In order to effectively control nonlinear and multivariable models, and to incorporate constraints (bounds, rate of change), a suitable controller is Model Predictive Control.

In this work, we present the results of the implementation of MPC on a general-purpose processor that provides a low-power, small in size and relatively inexpensive solution. The MPC operations are carried out on the general processor, while the solutions of the optimizations control [4] a glucose-insulin model [5] running on a desktop PC. Due to the insulin injections we manage to keep the glucose concentration between the desired limits, avoiding hyperglycemia that would result in the absence of control. The general purpose Motorola MPC555 processor is hosted on a Phytec board, used to provide the interfacing. In order to test the performance of MPC on the embedded target we use Processor-In-the-Loop (PIL) co-simulations. In PIL mode, a plant model runs in non-real-time on the host workstation in Simulink. Meanwhile, the MPC555 exchanges signals via RS232 serial communication with Simulink running on the workstation. At each sample interval, Simulink performs model updates and sends output signal data via RS232 to the MPC555.

In order to analyze the performance of MPC running on the particular board we use a profiler, that analyzes the amount of time the code spends performing various tasks of the optimization. Most of the profilers perform statistical sampling of the runtime environment; these profilers are called passive or sampling profilers. The main advantage of a passive profiler is that it requires no modification to the program under observation. In order to profile the performance of MPC running on the Motorola board, the profiler collects via the RS232 pathway data from the MPC555 target microcontroller, which is

running a suitably configured version of the optimization code--generated by the Embedded Target for Motorola MPC555. To examine the influence of the control horizon on the computational costs of MPC running on the Motorola processor, we set the number of optimizations at a fixed number and we provide profiling results for different cases of control and prediction horizons. Moreover, we provide profiling of the performance of MPC for different number of optimizations, having the control and prediction horizons fixed. Both these profiling results illustrate that we remain for all examined cases at under one second for the computation of the optimal insulin dosage using MPC. Thus the results indicate that the embedded MPC implementation can very easily to more complex models and larger optimization problems.

Acknowledgments: Partial financial support for this project from the U.S. National Science Foundation ("XYZ-on-Chip" initiative), the CTS-0134102 (CAREER program), and the Pittsburgh Digital Greenhouse is gratefully acknowledged.

[1] R. Langer. Transdermal drug delivery: past progress, current status, and future prospects. Advanced Drug Delivery Reviews, 56:557–558, March 2004.

[2] S. L. Taoa and T. A. Desai. Microfabricated drug delivery systems: from particles to pores. Advanced Drug Delivery Reviews, 55:315–328, March 2003.

[3] R. S. Parker and F.J. Doyle III. Control-relevant modeling in drug delivery. Advances in Drug Delivery Reviews, 48(2):211–248, 2001.

[4] R. S. Parker, F. J. Doyle III, and N. A. Peppas. A model-based algorithm for blood glucose control in type I diabetic patients. IEEE Transactions on Biomedical Engineering, 46(2):148157, 1999.

[5] A. Makroglou, J. Li, and Y. Kuang. Mathematical models and software tools for the glucose-insulin regulatory system and diabetes: an overview. To appear: Applied Numerical Mathematics.