LQG-Based Real-Time Scheduling and Control Codesign

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How can a computer control many systems at the same time?

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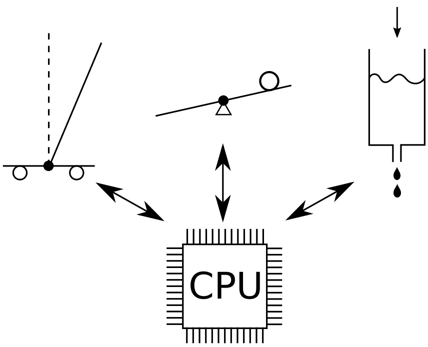
Popular science summary of the PhD thesis *LQG-Based Real-Time Scheduling and Control Codesign*, December 2017. The thesis can be downloaded from `www.control.lth.se/publications`.

In this thesis we study how to design multitasking control systems with good performance, utilizing the computer as efficiently as possible. For optimum results, we use algorithms from both computer science and control engineering.



A computer is used to simultaneously control three different systems: a pendulum on a cart, a ball on a beam, and a water tank.

What is a control system? Three examples are given in the figure to the left. In the upper left, we see an inverted pendulum. We can stabilize the pendulum in the upright position by applying a force to the cart to which the pendulum is attached. In the upper middle part of the figure, we see a ball that should be balanced on a beam. The position of the ball can be controlled by manipulating the tilt angle of the beam. In the upper right, we have a tank system. We can control the water level by setting the inflow to the tank. All of these systems require constant attention to remain stable and to operate with precision. The computer is a good substitution of manual labor if we can design an automatic control system and program the algorithms to run on its central processing unit (CPU).

As the figure suggests, a single computer can be used to control multiple systems at the same time. This is often a more cost-efficient solution than having separate computers for each automatic control system. If we take a closer look at how the CPU works, it internally uses *multitasking* to share the time between different activities. At each instant, there can be only one task running on the CPU, while the other tasks have to wait. This translates into extra delays for the control algorithms running on the CPU. Moreover, due to the multitasking, the delays will be time-varying and quite unpredictable.

The time-varying part of the delay is known as *jitter*. The larger the delay and jitter of a control task, the worse the performance will be. For instance, the inverted pendulum could start to oscillate or even fall down. If we prioritize one task, then that task does not have to wait for the others to finish. But at the same time, the others tasks' delays will be longer. So there is a trade-off between the performance of one controller and the performance of the other controllers.

Our goal in the thesis is to optimize the overall control performance. On one hand, we investigate how to schedule the CPU using different algorithms from computer science. For example, we assign different priorities and periods to the tasks. The most important task is assigned a high priority and a short period, so that the delay and jitter are small, and the control performance is good. In contrast, the least important task is assigned a low priority and a long period. But that may be OK if that control system is not so sensitive to delay.

On the other hand, we design controllers that take the scheduling into account, using algorithms from control engineering. With more detailed information about the delay and jitter, we are able to design controllers that give better control performance. The best results can be achieved when both perspectives are considered at the same time, resulting in so called *scheduling and control co-design*.

We saw three toy systems being controlled by one CPU in the figure above. Actually, many systems with similar properties are widely used in industry, where they are called real-time control systems. The applications range from cars to mobile music players, from robots to cameras, and from medical devices to communication systems. In all of these systems, our methods may help to save energy, use cheaper hardware, and also improve the control performance.