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# State feedback control of a rotary inverted pendulum

**Keywords:** LQR-control, pole-placement, inverted pendulum, balance control, reference tracking

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**Extended abstract.** Regulating a pendulum link to the upright position is an application of a mechanical balancing problem. An-other well-known example of such a balancing problem is Segway, where a controller has to prevent the machine from falling when a user shifts her center of gravity. The controller should also maintain a correct velocity of Seg-way depending on its angle from the upright position. This paper investigates linear state feedback control of a rotary inverted pendulum, which is attached to Quanser QUBE - Servo 2 base unit as in Figure 1.


**Figure 1.** Quanser QUBE - Servo 2 system

The system consists of a pendulum link and a rotary arm. The pendulum can spin freely around the rotary arm, which can be turned ±$90^\circ$ about its pivot point. The rotary arm is mounted to the base unit with magnets. The system has three measurements; namely, input voltage and angles of the rotary arm and the pendulum link. Quanser has implemented so-called "Swing-up" -control to the inverted pendulum system, which is used to raise the pendulum link to the upright position. Feedback controllers in this paper are designed to 1) regulate the pendulum link to upright position and 2) enable the rotary arm to turn from one angle to another while satisfying two restrictions. The first restriction concerns the DC motor input voltage, which is limited by $\pm 15V$. Additionally, the pendulum link must not deviate more than $20^\circ$ from its upper position, or the system could become unstable. For the above reasons, the problem considered in this paper is an example of simultaneous regulation task and a reference tracking scenario.

In this paper, two LTI-state feedback design tools are utilized; namely, the pole-placement method and the Linear-Quadratic-Regulator (LQR) control. With both of these tools, a stabilizing state feedback gain is obtained. The design methods produce separate controllers whose performances are evaluated based on settling time ($t_s$), rise time ($t_r$) and maximum overshoot ($M_p$) of responses. The best controller is simulated using Simulink software and tested with the actual device. The realized transient response characteristics of the system are $t_s$ = 3.90, $t_r$ = 0.966 and $M_p$ = 2.48.