

Precision Motor Control Development Using Rapid Control Prototyping Tools

E. Hill, R. Venugopal and V. G. Moudgal
dSPACE, Inc
22260 Haggerty Road, Suite 120
Northville, MI 48167
{ehill, rvenugopal, vmoudgal}@dspacedinc.com

Servo control of motor driven systems is one of the basic applications of control theory, and is a topic that has been extensively studied in the literature. However, several recent applications ranging from optical switching systems in communication networks to space-based precision pointing systems demand very high levels of performance and robustness. These requirements necessitate the design and implementation of high performance controllers within short development cycles. The use of Rapid Control Prototyping (RCP) tools significantly reduces the design, development and testing phases of new controllers, and thus enables a designer to meet tight time-to-market schedules. The ability to rapidly modify the structure and parameters of a controller is a key benefit of these tools. In this paper we describe the design and implementation of three control strategies on an optical sensing test-bed using RCP tools.

The test-bed consists of a DC brushless motor with a mirror mounted on it, a pulsed semiconductor laser and eight optical sensors. The objective is to slew the mirror in minimum time with a pointing accuracy sufficient to reflect the laser beam on to any specified optical sensor. The optical sensors are spaced 20 degrees apart at a radius of 15cm from the mirror. The mirror is directly mounted to the motor shaft via a specialized mounting fixture. The motor rotates the mirror so that the laser beam can illuminate each of the sensors. At each sensor, the laser is modulated to provide an eight-bit data stream. The sensors, and supporting circuitry, convert the light pulses into a TTL level electrical signal that can be monitored using digital inputs or an oscilloscope. After transmission of the data stream, the mirror rotates to the next detector and sends a new eight-bit data stream. Each sensor receives eight-bits of data at a minimum refresh rate of 100ms. The overall dimensions of the unit will be approximately 40cm wide by 20cm deep by 6cm tall. The unit will house the power supply, servo amplifier, and supporting electronic circuitry.

The paper describes the modeling, design, simulation and real-time implementation procedures used in the development of the control laws. PID and H_2 –optimal (LQG) controllers are tested and trade-offs between performance and design and implementation complexity are studied. A brief discussion on transitioning the concepts validated in the RCP environment to production is also included.

The tasks involved in the control system design process are

1. System Identification
2. Controller Design
3. Offline Simulation
4. Real-Time Implementation and Testing

System Identification: The electromechanical hardware in the system consists of a Computer Optical Products CM355 three-phase DC brushless motor with a 2048 line optical encoder attached to the shaft. The motor is driven by an Advanced Motion Controls current amplifier, which also handles the commutation of the three-phase signals. The controller is implemented on a dSPACE DS1103 controller board that feeds a reference voltage to the current amplifier.

The first task in designing the controller is to obtain a mathematical model of the system dynamics from amplifier voltage input to encoder position measurements. This task is accomplished by using system identification. The N4SID subspace algorithm is used for this purpose and is implemented using the MATLAB System Identification Toolbox. The input-output data used for system identification is obtained by driving the system with a random signal between +/-1V from the DS1103 and reading the encoder output. An unstable second-order state space model of the system dynamics is obtained using N4SID with an effort of 4 man-hours.

PID Controller Design: The control objective is to design a controller that achieves a 5% settling time of less than 50 milliseconds with a steady-state error of less than 0.4 degrees. Using the identified state-space model of the motor dynamics, a PID controller is tuned by running several simulations of the closed-loop in Simulink. Then, this controller is implemented on the DS1103 using the dSPACE Real-Time Interface to Simulink at a sampling rate of 10KHz. The figures below show the experimental closed-loop system response to a square wave input at 1 Hz. The effort required for this phase of the design was 4 man-hours.

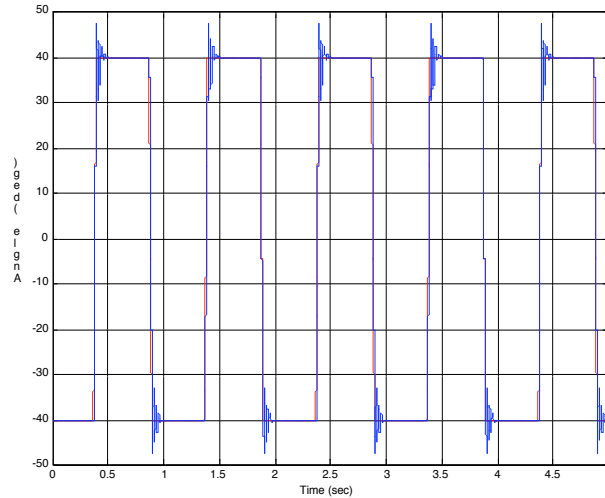
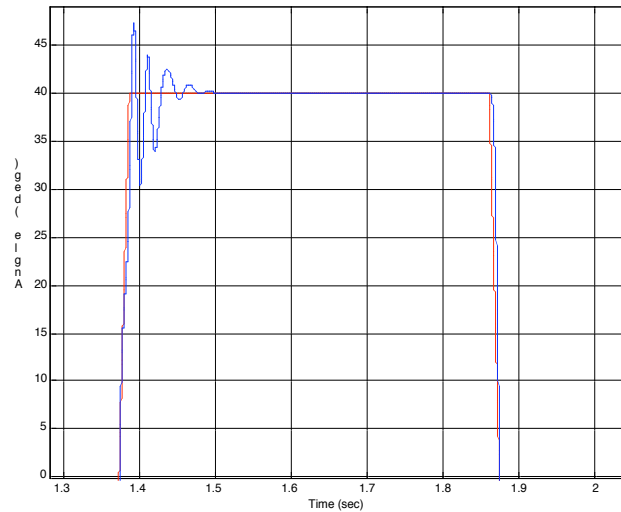


Figure 1: Closed-Loop Response of Motor with PID Controller. Solid Line: Shaft Position, Dashed Line:



Reference Command

Figure 2: Transient Response of Motor with PID Controller. Solid Line: Shaft Position, Dashed Line: Reference Command

From the plots, we can see that achieve the control objective with a 5% settling time of about 45 milliseconds and with a steady-state error of 0.2 deg. However, the system has an undershoot of about 12%.

LQG Controller Design: An H_2 –optimal (LQG) controller is designed using the MATLAB Control System Toolbox by calculating the optimal regulator gain matrix and the Kalman filter (observer) gain. The system matrices obtained from system identification are used to calculate these gains by solving the associated Riccati equations. Several simulations are performed in Simulink using the identified model and different choices of control and output weights. The controller that performs the best in terms of settling time and steady-state error is then implemented on the DS1103 controller board running at a sampling rate of 10 KHz. The experimental closed-loop performance is shown in Figures 3 and 4. The effort required for this phase of the design was 4 man-hours.

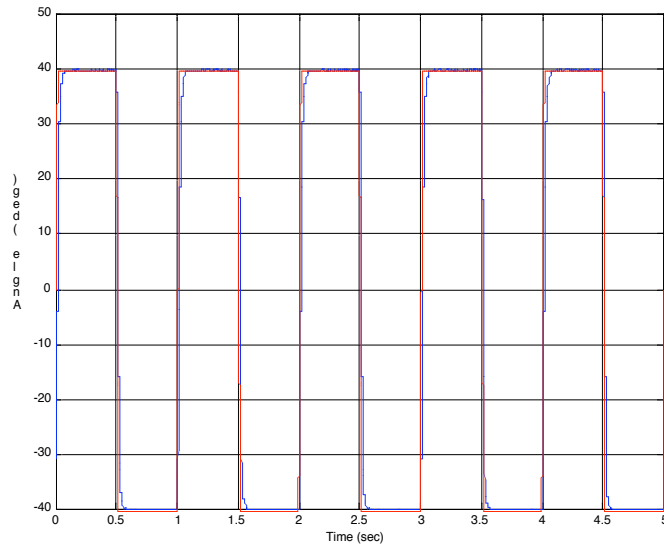


Figure 3: Closed-Loop Response of Motor with LQG Controller. Solid Line: Shaft Position, Dashed Line: Reference Command

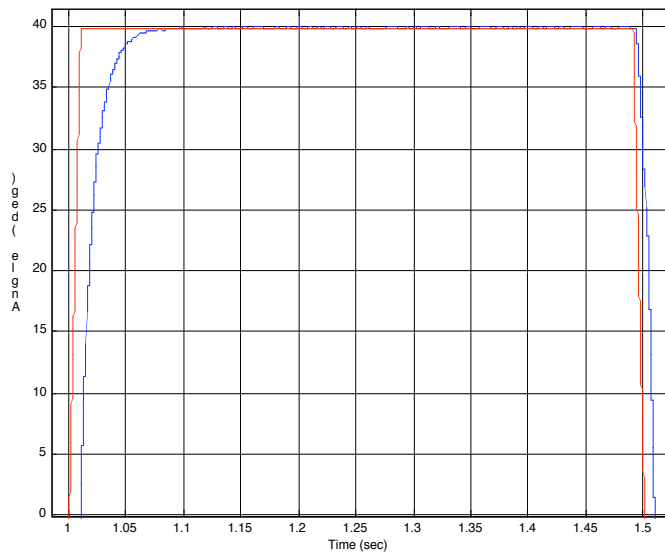


Figure 4: Transient Response of Motor with LQG Controller. Solid Line: Shaft Position, Dashed Line: Reference Command

The LQG controller achieves the control objective with a 5% settling time of 35 milliseconds and a steady-state error of 0.2 deg. It also shows a significant improvement in transient response characteristics compared to the PID controller with the output showing no overshoot.

Summary: This paper describes the use of Rapid Control Prototyping (RCP) tools for precision motion controller design. A test-bed for validating precision motion control concepts is described. We present results that use a combination of design and RCP tools to develop a state-space model of a DC brushless motor, and to design two controllers that meet steady-state response specifications using position feedback from an encoder. System identification, controller design and real-time experimental implementation for both controllers were achieved with an effort of 12 man-hours.