4 The Servo Loop

4.1 Overview

A servo loop is used as part of the basic method of determining the motor command output. The function of the servo loop is to match as closely as possible the commanded position, which comes from the trajectory generator, and the actual motor position.

To accomplish this, the profile generator commanded value is combined with the actual encoder position to create a position error, which is then passed through a digital PID-type servo filter. The scaled result of the filter calculation is the motor command, which is output as either a PWM signal to the motor amplifier, or a 16-bit input to a D/A Converter.

4.1.1 PID loop algorithm

The servo filter used is a proportional-integral-derivative (PID) algorithm, with velocity and acceleration feed-forward terms and an output scale factor. An integration limit provides an upper bound for the accumulated error. An optional bias value can be added to the filter calculation to produce the final motor output command. A limiting value for the filter output provides additional constraint.

The PID+Vff+Aff formula, including the scale factor and bias terms, is as follows:

\[
\text{Output} = K_p E_n + K_d \left( \dot{E}_n - E_{n-1} \right) + \sum_{j=0}^{n} E_j \times K_i / 256 + K_{vff} \left( \text{CmdVel} / 4 \right) + K_{aff} \left( \text{CmdAccel} \times 8 \right)
\]

\[\times K_{out} / 65536 + \text{Bias} \]

where \( E_n \) are the accumulated error terms, \( K_i \) is the Integral Gain, \( K_d \) is the Derivative Gain, \( K_p \) is the Proportional Gain, \( K_{vff} \) is the Acceleration feed-forward, \( K_{aff} \) is the Velocity feed-forward, Bias is the DC motor offset, \( K_{out} \) is the scale factor for the output command.

All filter parameters, the motor output command limit, and the motor bias are programmable, so that the filter may be fine-tuned to any application. The parameter ranges, formats and interpretations are shown in the following table:
4.1.2 Motor bias in closed-loop mode
The Motor bias is not used in closed-loop mode.

4.1.3 Output scaling
The Kout parameter is not used.

4.1.4 Integration Limit
The integration limit is used to place a boundary on the absolute value which is contributed to the PID output by the integration term. The Integration Limit is a fixed value and cannot be altered from the host.

4.1.5 Output limit
The motor output limit prevents the filter output from exceeding a boundary magnitude in either direction. If the filter produces a value greater than the limit, the motor command takes the limiting value. The motor limit value is set by the host. The motor limit applies only in closed-loop and open-loop modes.

4.2 Closed-loop and open-loop control modes
In addition however, turning the motor off, or having the motor be turned off automatically by the chip via a motion error, places the chip into what is known as 'open loop' mode. In open loop mode, the servo filter does not operate and the motor command output value is set manually by the host. With the motor 'on' the chip is in 'closed loop' mode and the motor command value is controlled automatically by the servo filter. Figure 4.2-1 shows the control flow for open and closed loop operation.
Closed-loop mode is the normal operating mode. Open-loop mode is typically used when the axis requires torque control only, or when the amplifier must be calibrated.

### 4.2.1 Motor bias in open-loop mode

The motor bias applies in open-loop mode. If the axis is switched to open-loop mode, the bias value is output to the motor. Once the host issues a new motor command, however, its value supersedes the bias output, which no longer has any effect. As soon as the axis returns to closed-loop mode, the bias changed.