The stroke amplitude is decreasing as the frequency increase. Above 30 Hz, the none-loaded response becomes null and therefore the stimulation is imperceptible. The cause might be the backlash between the motors axis and the slider contact plate. Nevertheless, the interface can provide a perceptible sensation from DC to 30 Hz.

Closed-loop Control

Since the actuators are speed-controllable, we used closed loop control of the slider position to ensure the deformation of the finger. This loop was implemented on the main microcontroller and runs at 2 kHz

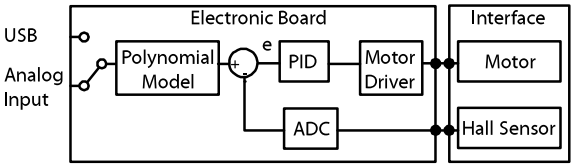

Fig. 8: *Control loop scheme*

Diagram of the closed-loop control is shown at Fig. 8. The setpoint is read by the control board from analog input or usb. The setpoint is compared with the measured position to calculate an error e. A PID controller sends velocity command to the motor driver. A Hall sensor measures the current position of the slider equipped with a magnet. The Hall sensor voltage is read by a 10 bit analog to digital converter (ADC).

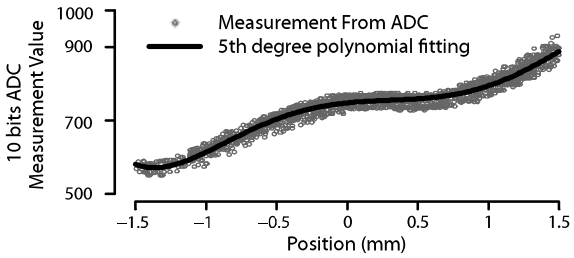

Fig. 9: *Polynomial fitting of the hall sensor measurements.*

The relation between the position and the sensor is not linear so the ADC measurements have been calibrated with the laser telemeter to create a 5th degree polynomial approximation that converts desired position into digital value (see *Fig. 9*). With this hall sensor and its ADC, the interface can achieve a 10 µm positioning resolution.

Conclusion and outlook

The 0.6 N stall force and the 3 mm stroke are well suited for quasi-static stimulation like static contacts, grips and a number of haptic effects operating in the low frequencies such the simulation of small virtual bumps and features [10]. However the low frequency cut-off makes them incompatible with the simulation fast tactile events such as roughness or slippage. To overcome this issue, one could propose to combine the present actuator technology with another having a smaller stroke response but which could respond to faster signals, i.e. from 30 to 250 Hz.

In order to provide even richer interaction, a 2-degrees-of-freedom version is in preparation. This interface will be able to shear the fingertip in both directions with the same performance that the one presented in the present article.

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