University of California at Irvine
Mechanical Systems Laboratory
Data Acquisition

Note: These notes are derived from Ch. 8 Data Acquisition, Introduction to Mechatronics and Measurement Systems, 2nd Edition, David G. Alciatore and Michael B. Histand, McGraw-Hill 2003
See also p. 563-564 in Palm's System Dynamics.

Experimental Apparatus

In robotics and mechatronics, and in modern experiments with mechanical and aerospace systems, you use a computer to acquire data from sensors, process the data, and send signals to control actuators:

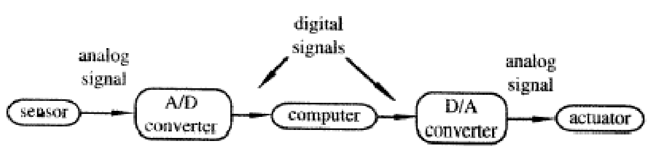


Figure 8.13 Computer control hardware.

The computer could be:

- a PC with a data acquisition card installed. A data acquisition card is sort of like a "video card", except it inputs and outputs arbitrary analog signals instead of a video signals. The data acquisition card can also be a separate module outside of the computer. For example, a "Labjack" is a data acquisition card that communicates with the computer through the USB port.
- a microcontroller, which is a computer on a single chip, like the Arduino. A digital signal processing chip is similar to a microcontroller.
- a programmable logic controller (PLC), which is a specialized industrial device for interfacing to analog and digital devices. PLC's are typically programmed with ladder logic, which is a graphical language for connecting inputs, outputs, and logic.
- Digital circuits, made with logic gates (e.g. AND, OR, NOT gates), or programmable logic arrays, which allow you to set-up arrays of logic gates.

Sampling, the Nyquist Frequency, and Aliasing

Many types of sensors (e.g. potentiometers, tachometers, accelerometers, force transducers) provide analog (i.e. continuous) voltage outputs, and many types of actuators (e.g. dc brushed motors) require analog inputs. Computers represent numbers using sequences of digital voltages (i.e. sequences of "bits"). Digital voltages (or "bits") can take only two discrete values, logical 0 (typically corresponding to 0 volts) and logical 1 (typically corresponding to 5 volts). Getting analog signals into the digital form usable by computers requires two processes: sampling and quantization.

Sampling refers to evaluating an analog signal at discrete instants in time. The sampling frequency (or sampling "rate") is how many times per second the signal is sampled.

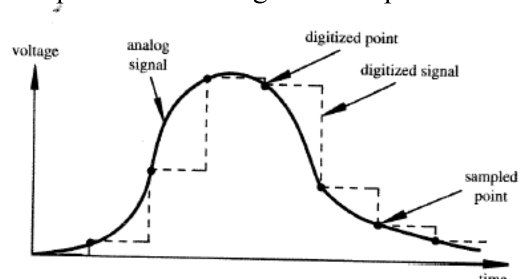


Figure 8.1 Analog signal and sampled equivalent.

The Nyquist sampling theorem states that you must sample a signal at a frequency that is twice the maximum frequency in the signal (i.e. at the "Nyquist Frequency"), in order to preserve all of the information in the signal. If a signal is sampled at less than this frequency, "aliasing" happens. The result of aliasing is that a high frequency signal looks like a lower frequency signal.

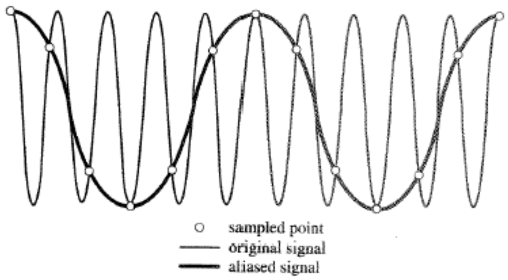
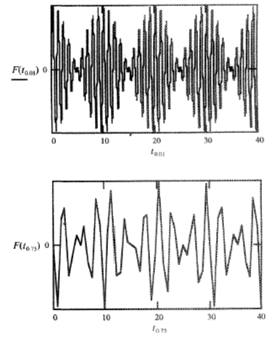


Figure 8.2 Aliasing.

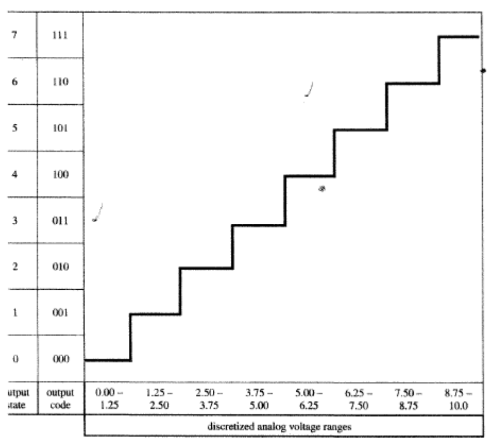


Effect of Sampling Rate on Control Stability

Sampling introduces delays into a control system. If the sampling rate is high enough, the delay is negligible. But if sampling rate is low (e.g. < 100Hz for a robot), then the associated delay can make the control system unstable, especially for large feedback gains. Delay essentially causes "the right information" to be delivered at the wrong time.

Quantizing Theory

Quantizing transforms a continuous, analog input into a set of discrete output states. Coding is the assignment of a digital code word or number to each output state.



Analog-to-Digital Conversion (A/D)

An A/D converter quantizes an analog signal at some sampling rate, which is determined by a "trigger signal" from the computer. The resolution of the A/D converter is the number of bits that it uses to represent the analog value of the input. The number of possible states N is equal to the number of bit combinations that can be output from the converter: $N=2^n$. Most commercial A/D converters are 8, 10, or

12 bit devices that resolve 256, 1024, and 4096 output states, respectively. Here is a flash AD converter:

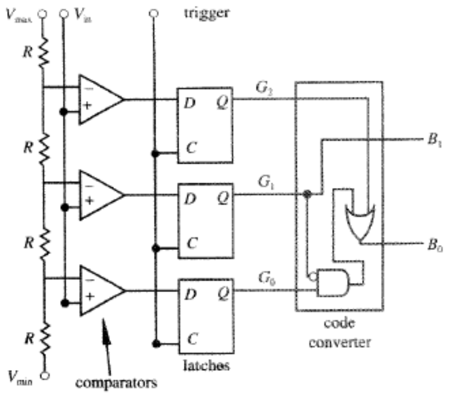


Figure 8.10 A/D flash converter.

Table 8.1 2-bit flash converter output

State	Code ($G_2G_1G_0$)	Binary (B_1B_0)	Voltage range
0	000	00	0–1
1	001	01	1–2
2	011	10	2–3
3	111	11	3–4

Digital-to-Analog (D/A) Conversion

A D/A converter takes the binary representation of a signal and converts it into an analog output signal. A ladder D/A Converter works like this:

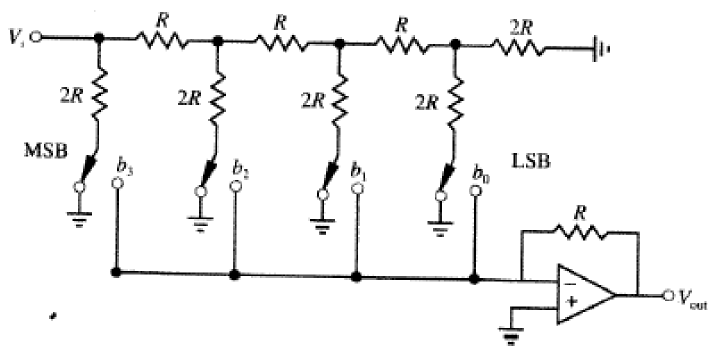


Figure 8.11 4-bit resistor ladder D/A converter.

Pulse-Width Modulation

Some microcontrollers don't have D/A converters. The Arduino, for example, can only output 0 V or 5 V. To do D/A conversion with an Arduino, we will use Pulse-Width Modulation (PWM). PWM consists in sending a set of pulses at high frequency. We divide each period in two intervals, the ON part (pulse) and the OFF part. The term "duty cycle" describes the percentage of ON time compared to a full period. Therefore, a signal with a 0% duty cycle is always OFF while one with a 100% duty cycle is always ON. If we low pass filter this PWM signal with a filter with an appropriate time constant, the resulting signal is approximately a constant voltage that is proportional to the duty cycle. We can then use this resulting signal similar to an analog output. Note that because many physical objects (like motors) already act like low pass filters, you might not even need to incorporate a separate low pass filter – the object itself will serve that purpose.