

T H E

INDUSTRIAL ELECTRONICS

H A N D B O O K

Editor-in-Chief

J. DAVID IRWIN



CRC PRESS



IEEE PRESS

A CRC Handbook Published in Cooperation with IEEE Press

70-672
19-127

Coventry University

Library of Congress Cataloging-in-Publication Data

The industrial electronics handbook/edited by I. David Irwin.
p. cm.-(The electrical engineering handbook series)
Includes bibliographical references and index.
ISBN 0-8493-8343-9 (alk. paper)
1. Industrial electronics--Handbooks, manuals, etc. I. Irwin, I. David, 1939-. II. Series.
TK7861.I52 1996
621.3-dc20

96-3070
CIP

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International Standard Book Number 0-8493-8343-9
Library of Congress Card Number 96-3070

Printed in the United States of America 1 2 3 4 5 6 7 8 9 0
Printed on acid-free paper.

70-672
10-12

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6.9 Digital Signal Processing

Belle Upadhyaya

Introduction

Signal processing deals with the analysis of stationary and non-stationary measurements acquired from sensors used for monitoring, control, and diagnostics of process systems. Digital signal processing (DSP) is the technology of analyzing signals that are digitized or discretized at a certain specified sampling rate. The primary goal of DSP is to extract information about the operation of a component or a system with applications to: monitoring, diagnostics, control, predictive maintenance, estimation of performance-related parameters, pattern recognition, sensor validation, and many others.

The area of signal processing grew out of the needs in aerospace, communications and defense applications beginning in the late 1930s. Because of the advent of fast and efficient digital computers and advances in data acquisition and instrumentation systems, the DSP technology has been changing continuously and has made tremendous advances. DSP is being used in all areas of science and engineering. Some examples are: aerospace industry, communications industry, underwater acoustics, vibration analysis, power plant applications, chemical, metals and other process industries, medical diagnostics, robotics, and image and pattern analysis.

This section presents the fundamentals of data acquisition and analysis of process signals, and system monitoring using the DSP techniques. The emphasis is on processing stationary random signals.

Data Acquisition from Sensor and Sampling Requirements

The steps in data acquisition consist of the following:

1. Sensor placement and verifying its output.
2. Signal preconditioning such as filtering and amplification.
3. Signal recording using analog or digital devices.
4. Data qualification and storage.

Figure 6.34 shows a schematic of a data acquisition system where the signals are sampled and stored in a PC. If a large

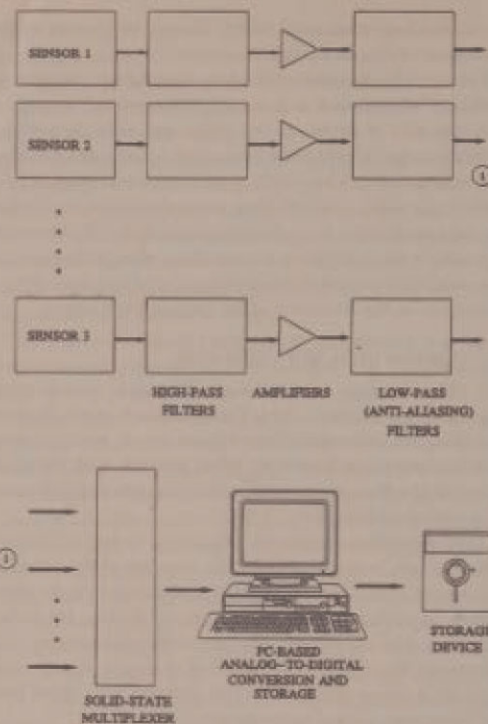


Figure 6.34 Data acquisition system showing signal conditioning devices, signal multiplexer and PC-based A/D conversion.

number of signals has to be digitized, a solid state multiplexer may be used to reduce the number of digitizing channels and the cabling requirement.

Data Collection/Masurement

Physical variables are converted by transducers into proper electrical outputs, generally voltage. Examples of sensors used in process industry are thermocouples, resistance temperature detectors, pressure transmitters, accelerometers (for mechanical vibration), neutron detectors, thickness gauges, strain gauges, current probes, and many others. Nonlinearities, phase shifts, and gain changes are sources of error in an instrument channel.

Signal Conditioning

Before signals from the sensor system are digitized, it is necessary to prepare the signal input to the analog-to-digital (A/D) converter. Noise filtering and signal amplification are two of the conditioning important to improve the quality of the recorded data.

A high-pass (HP) filter is used to remove frequency components below a certain value, f_H (Figure 6.35). The purpose of the HP filtering is to remove DC levels and very-low-frequency components that are not indicative of the dynamics of the system being monitored. An example of high-pass filter setting for a

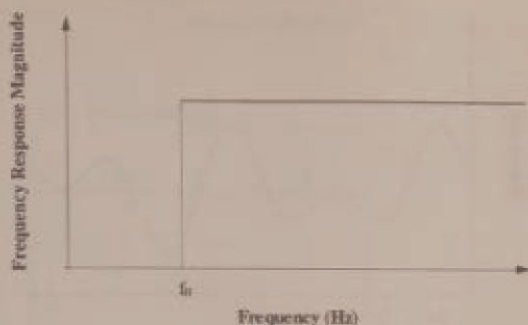
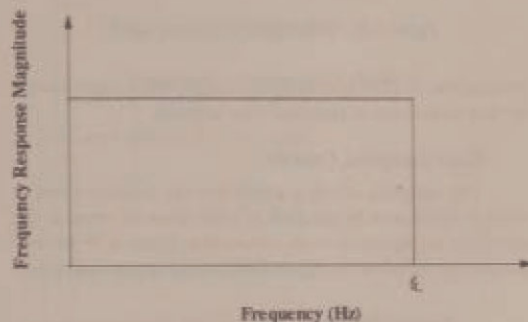


Figure 6.35 Illustration of high-pass (HP) filtering.

Figure 6.36 Illustration of low-pass filtering. The combination of HP and LP filters results in a band-pass filter. The pass band = $f_H - f_L$.

thermocouple or a pressure sensor is 0.01 Hz. A low-pass (LP) filter is used to remove frequency components above a certain value, f_L (Figure 6.36). A low-pass filter is also referred to as an anti-aliasing filter (see Data Sampling Criterion). The purpose of LP filtering is to remove frequency components of a signal above a specified frequency. The HP filtering enables us to amplify the dynamic component of the signal, so that the accuracy in A/D conversion is very high. The LP filtering removes unnecessary higher frequency components and enables us to choose a sampling rate that avoids any "distortions" in the digitized signal. An example of low-pass filter setting for a pressure transmitter signals is $f_L = 20$ Hz.

Before the filtered signal is digitized, the signal is amplified using drift-free amplifiers. The purpose of signal amplification is to increase the signal voltage range to match with the A/D converter range, so that the resolution of the digitized signal is high, and the quantization error is low. Figure 6.37 illustrates the effect of signal conditioning.

Filter and amplifier hardware devices are manufactured by several companies in the United States, Japan and Europe. Analog low-pass and high-pass filters with four to eight pole Butterworth filter design are very common. These filters have good frequency cut-off characteristics and also minimize the side-band effects

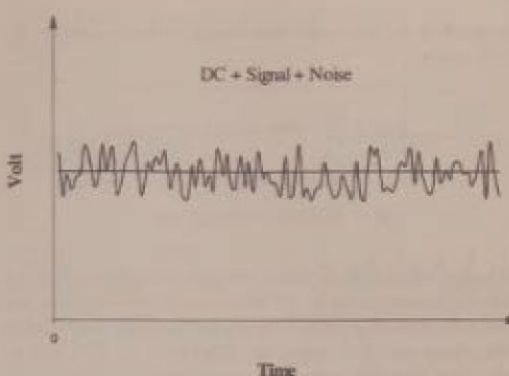


Figure 6.37 Illustration of signal conditioning using high-pass and low-pass filtering and amplification.

in the frequency-domain behavior. Vendors of predictive maintenance equipment and companies specializing in signal conditioning equipment, supply filters, amplifiers and other devices to meet required specifications.

Multiplexing of Signals

If the number of signals to be digitized is large compared to the number of A/D converters, it is often desirable to use a device to transmit signals using a single cable but interrupt the transmission of signals at certain preset time intervals. To be more effective in data digitization, the configuration shown in Figure 6.34 must be used. A multiplexer allows the flow of signals in time sequence, instead of simultaneously.

Signal multiplexing after amplification (high-level multiplexing) and the use of high-speed solid state switches have the advantages of minimizing source impedance, switch resistance, frequency limitation and thermal-induced voltages. The capital cost of signal conditioning and high-performance multiplexers is high, but will pay off in the long term. Multiplexing also avoids the need for running individual cables from instrument channels to the end recording devices.

Analog-to-Digital Conversion

Analog-to-digital converters (ADCs) are used to transform an analog signal into a discrete or sample valued signal, with a specified number of samples per second. This sampling rate and the design of the ADC must be such as to minimize the error in the digitized data.

In an analog-to-digital conversion, the value of a signal is converted into a discrete level. The resolution of the discrete level is defined by ADC output code as n bits. The number of discrete levels (or bins) represented by this ADC is 2^n . For a 12-bit ADC, the number of discrete levels is $2^{12} = 4096$. If FS is the full scale