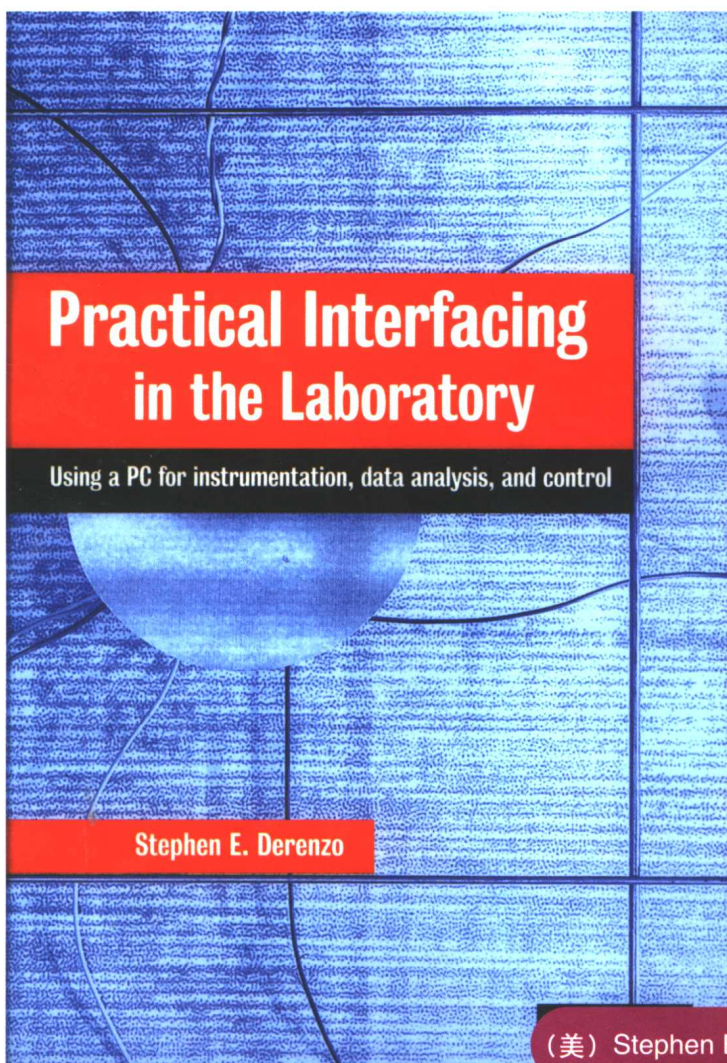


# 微机接口技术实验教程

(英文版)



(美) Stephen E. Derenzo 著



机械工业出版社  
China Machine Press

经典原版书库

# 微机接口技术实验教程

(英文版)

Practical Interfacing in the Laboratory  
Using a PC for Instrumentation, Data Analysis, and Control

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(美) Stephen E. Derenzo 著



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**Dedicated to:**

**My mother, Alice, and my father, Stanley**  
for their lifelong support and encouragement

**My brother, David**  
for our good times together

**My wife, Carol**  
for being my partner, wife, friend, and adviser

**My children, Jennifer and Julia**  
for reminding me of the joy of youth

**My students and teaching associates**  
who, over the years, helped improve the  
laboratory exercises and pointed out my errors

# Preface

This text describes in practical terms how to use the microcomputer to sense real-world quantities such as temperature, force, sound, light, etc., to analyze the data rapidly, to display the results, or to use the results to perform a control function. It was written for practicing engineers and scientists, and as a textbook for laboratory courses in electronic transducers and microcomputer interfacing.

Our approach takes full advantage of the availability of relatively low-cost microcomputers that are powerful enough to support high-speed parallel input/output (I/O) ports, data-acquisition circuit boards, graphical operating systems, high-level programming languages, and fast double-precision calculations. This book shows in practical terms the range of problems in data acquisition, analysis, display, and control that can be tackled in a cost-effective manner without delving into the bus protocol or native language of a particular microprocessor.

The book contains five chapters, covering digital tools, analog tools, conversion between analog and digital signals, sensors and actuators, and data analysis and control. The 27 laboratory exercises can be used either in a college-level laboratory course or as working examples for practicing engineers and scientists who wish to apply sensor, low-level amplification, and microcomputer principles in their work in a practical and immediate way.

This material was developed for two one-semester laboratory courses in the Electrical Engineering and Computer Science Department at the University of California in Berkeley, EECS 145L: "Electronic Transducer Laboratory" and EECS 145M: "Microcomputer Interfacing Laboratory." The purpose of these two courses is to provide upper-level undergraduate students with the tools needed to sense and control "real-world" quantities, such as temperature and force, as well as to display the results of "real-time" analyses, such as least-squares fitting, the Student's  $t$  test, fast Fourier transforms, digital filtering, etc. **It is assumed that the students have had some exposure to elementary analog and digital electronics, differential calculus and linear algebra, and the C programming language.**

Over the years, we have used several different microcomputer systems in the laboratory, and the laboratory exercises were designed to be as machine-independent as possible. Special instructions (such as Appendices E and F) were provided for the



particular counter/timer, parallel I/O port, and data-acquisition board that were used. A recent advance is software support in the form of C-callable drivers that make it relatively easy to perform single-word and block-data acquisitions and transfers in the Windows NT environment.

The C programming language was chosen because it is available for almost all microcomputers and is well-suited to data acquisition, analysis, and control. It provides word and byte I/O, bit manipulation, powerful conditional branching and data structures, a wide choice of accuracy and bit length for integer and floating point numbers, and high-speed execution.

Chapter 1, "Digital tools," briefly describes the overall organization of the microcomputer, binary and 2's complement number systems, and the digital components needed to perform data acquisition and control, such as digital timers, latches, registers, tri-state buffers, and parallel I/O ports. It goes on to describe the digital and control aspects of several data-acquisition procedures, and discusses the level of handshaking needed for various applications.

Laboratory Exercise 1 introduces the Windows NT operating system, the C compiler/editor, and the many ways that binary bit patterns can be interpreted as numerical quantities. Laboratory Exercise 2 provides examples using the microprocessor timer to measure human reaction times, and Laboratory Exercise 3 introduces the parallel I/O ports, reading switches, and controlling lights.

Chapter 2, "Analog tools," covers commonly used op-amp circuits, the instrumentation amplifier used for low-level differential amplification of sensor signals, noise sources, and the analog signal processing that can be used to enhance the signal-to-noise ratio. It goes on to describe a class B power amplifier that can be used to drive actuators.

Laboratory Exercises 4 and 5 explore op-amp circuits, instrumentation amplifiers, differential amplification, and noise sources, including electromagnetic interference. Laboratory Exercise 6 explores analog signal processing using the op amp, including active high-pass, low-pass, and notch filters.

Chapter 3, "Analog  $\leftrightarrow$  digital conversion," covers the data-conversion components needed to perform data acquisition and control, such as digital-to-analog (D/A) and analog-to-digital (A/D) converters, the sample-and-hold amplifier, and the comparator. It describes the commonly used methods for data sampling and introduces the notion of frequency aliasing resulting from inadequate sampling. (Considerations of aliasing in the Fourier domain are deferred to Chapter 5.) Chapter 3 lists and describes several commercially available circuit boards.

Laboratory Exercise 7 uses a commercial analog I/O board to provide an overview of both digital-to-analog and analog-to-digital conversion for those students who will not be doing Laboratory Exercises 8 and 9. The conversion between analog and digital is explored in Laboratory Exercises 8 and 9, using D/A and A/D integrated circuit chips. Laboratory Exercise 8 involves interfacing a D/A converter to a parallel input

port and waveform generation. Laboratory Exercise 9 involves interfacing an A/D converter to a parallel output port, using a hardware “strobe” and “ready for data” and “data available” handshaking protocol. Laboratory Exercise 10 uses a commercial data-acquisition board for the periodic sampling of waveforms and demonstrates the concept of frequency aliasing in the time domain.

Chapter 4, “Sensors and actuators,” covers the sensors (the first element in many data-acquisition systems), the real-world quantities that they sense, the nature of the signals (and the noise) that they produce, and actuators (essential in any control system).

Laboratory Exercises 11–14 explore the basic electronic transducers used to measure position, temperature, strain, force, and light. The thermoelectric heat pump is explored in Laboratory Exercise 15. Laboratory Exercise 16 investigates the ac and dc electrical properties of bare metal and Ag(AgCl) electrodes. Laboratory Exercises 17–19 explore physiological signals from the heart, skeletal muscles, and eyes.

Chapter 5, “Data analysis and control,” covers data analysis, including statistical analysis; Student’s  $t$  test; least-squares and Chi-squared fitting; continuous, discrete, and fast Fourier transforms, and some algorithms used for the control of real-world quantities.

Laboratory Exercise 20 explores analog-to-digital conversion for the storage of analog signals, digital-to-analog conversion for the analog recovery of those signals, and least-squares fitting for determining the accuracy of signal recovery. Laboratory Exercise 21 involves the sampling of sine, square, and triangle waves and the computation of their fast Fourier transforms (FFT). These techniques are applied in Laboratory Exercise 22 to the sampling and FFT of the human voice. Laboratory Exercise 23 compares analog to real-time digital filtering and Laboratory Exercise 24 demonstrates how the microcomputer can measure the impulse response of a linear, time-invariant system and use FFT techniques to determine the digital filter that can compensate for signal distortion caused by the system, provided that the frequency response of the system meets certain requirements. Laboratory Exercise 25 provides experience with analog temperature sensing and control. Laboratory Exercise 26 provides experience with computer-based digital temperature sensing and control using an electrical resistance oven and several algorithms. Laboratory Exercise 27 is similar to Laboratory Exercise 26, except that a thermoelectric heat pump is used with both the ability to heat and cool actively. An essential component is the LM12 power op amp.

In several laboratory exercises, a number of related circuits are built and examined. The *equipment* lists at the beginning of these exercises include all the parts needed for the students to build all the circuits before coming to the laboratory. As laboratory time is usually very limited, this approach works better than providing only the minimum number of parts needed and having the students dismantle one circuit during the laboratory period before they can build the next.

Each chapter is provided with problems derived from those used in midterm and final examinations.

Defined terms appear in the index followed by the word (definition) and the page number where they are first used. On that page, the term appears in bold face in the text that defines it.

Appendix A provides some physical and electronic units and constants for the problems at the end of the chapters, and Appendix B discusses issues of error propagation, and electrical shielding and grounds. Appendix C summarizes some hints useful in C programming. Appendix D provides C code listings and flow charts of some numerical methods, including the fast Fourier transform, nonlinear function minimization (used to fit curves to data), numerical integration using adaptive quadrature, and function inversion using both Newton's method and quadratic approximation. A program to compute the probability of exceeding Student's  $t$  is given as an example.

Appendix E describes the hardware and software needed to use the Data Translation DT3010 PCI plug-in board, and Appendix F describes how to use HP VEE to record waveforms on a digital oscilloscope. Appendix G discusses some potential electrical hazards and methods used to prevent them. Appendix H lists standard resistor and capacitor values and provides resistor color codes. Appendix I lists the ASCII character codes. Last is a glossary defining the technical terms used in the book.

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## Guide for the instructor

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Although the entire book would serve for a full-year course, it is also possible to cover portions of the material in separate one-semester courses, as we do at Berkeley.

A one-semester course on *digital interfacing, data analysis, and control* would include Chapters 1, 3, and 5, and Laboratory Exercises 1–3, 8–10, 20–24, and 26 or 27.

A one-semester course on *sensors, low-level amplification, and analog signal processing* would include Chapters 2 and 4, and Laboratory Exercises 4–6 and 11–19. Portions of Chapter 5 and Laboratory Exercise 25 would provide an introduction to analog control.

A one-semester course on *bioengineering* would include Chapters 2, 4, and 5, and selections from Laboratory Exercises 2, 4–7, 11–19, and 20–22, depending on course emphasis.

A solutions set is available for this book – contact [solutions@cambridge.org](mailto:solutions@cambridge.org) for details.



# Acknowledgments

I am indebted to Kenneth Krieg, who was the cofounder of EECS 145M "Microcomputer Interfacing Laboratory" and, as teaching associate over a period of several years, made important contributions to most of the laboratory exercises. I also thank the numerous teaching assistants and students who contributed to the improvement of the laboratory exercises.

Special thanks to Professor Ted Lewis for contributions to Chapter 4, derived from his course EECS 145A, "Sensors, actuators, and electrodes," and to Dr Thomas Budinger for contributions to Chapter 5, derived from his course EECS 145B, "Computer applications in biology and medicine." Some of the laboratory exercises were derived from EECS 182, "Biological signals and transducers," developed by Professors Ted Lewis and Ed Keller at Berkeley during the 1970s, and to them I am grateful. I also thank John Cahoon, Matt Ho, and William Moses for discussions of circuit design, Ronald Huesman and Gerald Lynch for discussions of statistical analysis and fitting, and to Orin Dahl for discussions of pseudo-random number generators.

# Contents

<i>Preface</i>	xi
<i>Acknowledgments</i>	xv

---

## **1 Digital tools**

---

1.1	Introduction	1
1.2	The microcomputer	2
1.3	Number systems	5
1.4	Digital building blocks	8
1.5	Digital counters/timers	13
1.6	Parallel and serial input/output ports	18
1.7	Digital data-acquisition procedures	29
1.8	Switch debouncing	33
1.9	Digital interfacing standards	35
1.10	Problems	44
1.11	Additional reading	51

### **Laboratory exercises**

1.	Introduction to C programming	53
2.	Measuring event times	58
3.	Digital interfacing: switches and lights	66

---

## **2 Analog tools**

---

2.1	Introduction	75
2.2	Operational-amplifier circuits	76
2.3	Op-amp characteristics	85
2.4	Instrumentation and isolation amplifiers	89

2.5	Noise sources	94
2.6	Analog filtering	98
2.7	The power amplifier	117
2.8	Problems	118
2.9	Additional reading	127

### **Laboratory exercises**

4.	Operational-amplifier circuits	128
5.	Instrumentation amplifiers	136
6.	Analog filtering	145

---

## **3 Analog $\leftrightarrow$ digital conversion and sampling** **153**

---

3.1	Introduction	153
3.2	Digital-to-analog converter circuits	153
3.3	Analog-to-digital converter circuits	161
3.4	The sample-and-hold amplifier	173
3.5	Sampling analog waveforms	180
3.6	Frequency aliasing	183
3.7	Available data-acquisition systems	186
3.8	Problems	187
3.9	Additional reading	200

### **Laboratory exercises**

7.	Introduction to A/D and D/A conversion	201
8.	D/A conversion and waveform generation	206
9.	A/D conversion and periodic sampling	213
10.	Frequency aliasing	221

---

## **4 Sensors and actuators** **226**

---

4.1	Introduction	226
4.2	Position and angle sensors	228
4.3	Temperature transducers	234
4.4	Strain-sensing elements	253
4.5	Force and pressure transducers	255
4.6	Measuring light	261
4.7	Producing visible light	268

4.8	Ionic potentials	271
4.9	The detection and measurement of ionizing radiation	274
4.10	Measuring time	277
4.11	Problems	278
4.12	Additional reading	298

### **Laboratory exercises**

11.	Measuring angular position	300
12.	Measuring temperature	305
13.	Measuring strain and force	311
14.	Measuring light with a photodiode	316
15.	The thermoelectric heat pump	322
16.	Electrodes and ionic media	329
17.	The human heart	334
18.	The electromyogram (EMG)	343
19.	The electrooculogram (EOG)	352

---

## **5 Data analysis and control** **360**

---

5.1	Introduction	360
5.2	The Gaussian-error distribution	360
5.3	Student's $t$ test	366
5.4	Least-squares fitting	372
5.5	The chi-squared statistic	375
5.6	Solving nonlinear equations	379
5.7	Monte Carlo simulation	383
5.8	Fourier transforms	385
5.9	Digital filters	415
5.10	Control techniques	419
5.11	Problems	427
5.12	Additional reading	448

### **Laboratory exercises**

20.	Analog $\leftrightarrow$ digital conversion and least-squares fitting	449
21.	Fast Fourier transforms of sampled data	454
22.	Fast Fourier transforms of the human voice	461
23.	Digital filtering	471
24.	Process compensation using Fourier deconvolution and digital filtering	477
25.	Analog temperature control using a resistive heater	485

26. Temperature control using the computer and a resistive heater	490
27. Temperature control using the computer and a thermoelectric heat pump	497
<b>Appendix A</b> Grounding and shielding	504
A.1 Introduction	504
A.2 Interference noise due to common impedance	504
A.3 Interference noise due to capacitive coupling	505
A.4 General rules to follow	506
<b>Appendix B</b> Experimental uncertainties	508
B.1 Multimeter accuracy	508
B.2 Propagation of random error	508
<b>Appendix C</b> C programming tips	510
C.1 Declare all variables	510
C.2 Arithmetic statements	510
C.3 Conditional tests	511
C.4 Conditional operators	511
C.5 Indexed looping	511
C.6 Bitwise logical operators	512
C.7 Increment and decrement operators	512
C.8 The printf statement	513
C.9 Defining your own functions	513
C.10 "Including" your own functions	514
C.11 Opening and writing to files of arbitrary name	515
C.12 Using library functions	515
C.13 Allocating large storage arrays	516
C.14 General format rules for C programs	516
<b>Appendix D</b> Numerical methods and C functions	517
D.1 Introduction	517
D.2 Fast Fourier transform	517
D.3 Minimization function PARFIT	520
D.4 The uncertainty estimation function VARFIT	529
D.5 Numerical evaluation of functions defined by integrals	542
D.6 Function inversion using Newton's method	549
D.7 Function inversion using quadratic approximation	549
D.8 Random number generator	550
<b>Appendix E</b> Summary of Data Translation DT3010 PCI plug-in card	553
E.1 Introduction	553
E.2 Parallel output	553
E.3 Parallel input	556

E.4	Analog output	556
E.5	Analog input	557
E.6	Using the DT3010 board with the Microsoft visual C++ compiler	557
<b>Appendix F</b>	<b>Using the digital oscilloscope to record waveforms</b>	<b>558</b>
F.1	Introduction	558
F.2	Capturing the waveform	558
F.3	Printing the waveform	558
<b>Appendix G</b>	<b>Electrical hazards and safety</b>	<b>560</b>
G.1	Introduction	560
G.2	Electrical power	561
G.3	The ground fault interrupter circuit	563
G.4	The isolation transformer	564
G.5	Typical accident scenarios	564
G.6	Methods of accident prevention	564
<b>Appendix H</b>	<b>Standard resistor and capacitor values</b>	<b>566</b>
H.1	Standard resistor values and color codes	566
H.2	Standard capacitor values and codes	566
<b>Appendix I</b>	<b>ASCII character codes</b>	<b>569</b>
I.1	ASCII character set codes	569
	<i>Glossary</i>	572
	<i>Index</i>	602



# 1 Digital tools

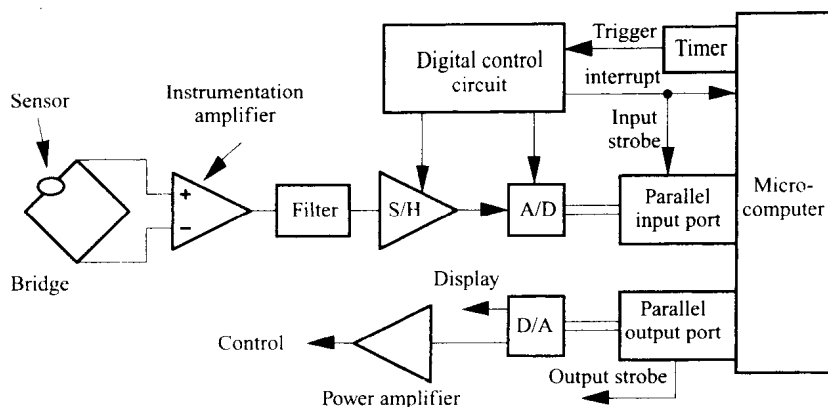
## 1.1 Introduction

In the past few years, enormous advances have been made in the cost, power, and ease of use of microcomputers and associated analog and digital circuits. It is now possible, with a relatively small expenditure, to purchase a microcomputer system that will take data, quickly analyze them, and display the results or control a process. This has been made possible by the development of technology that can fabricate millions of transistors, diodes, resistors, capacitors, and conductors on a single silicon **integrated circuit chip**.

Normally, the microcomputer is equipped with a number of standard items: the microprocessor chip and associated circuits, random-access memory chips, removable floppy and cartridge disk drives, magnetic hard disk drives, optical disk drives, keyboards, video display screens, serial interfaces, printers, and  $x$ - $y$  entry devices such as the mouse, trackball, joystick, bitpad, and touch-sensitive display screen. However, data acquisition and control require additional components, such as digital and analog input/output (I/O) ports, and counters/timers. Analog input ports contain analog multiplexers, sample-and-hold (S/H) amplifiers, and analog-to-digital (A/D) converters. Analog output ports contain digital-to-analog (D/A) converters.

Even for designs requiring only a microprocessor and a few additional circuits, there are considerable advantages to using the resources of the microcomputer during the development stage. These include program code editors and compilers, an operating system for the storage and manipulation of code and data files, and ample random-access memory.

In this chapter, we discuss digital interfacing concepts used in microcomputer-based data-acquisition and control systems (Figure 1.1), including parallel and serial input/output ports, handshaking, and digital counters/timers. Analog tools (amplification and filtering) are treated in Chapter 2, digital-to-analog and analog-to-digital conversion and sampling in Chapter 3, and sensors and actuators in Chapter 4.



**Figure 1.1** A microcomputer system interfaced to sensors and associated analog circuits for data acquisition, analysis, and control.

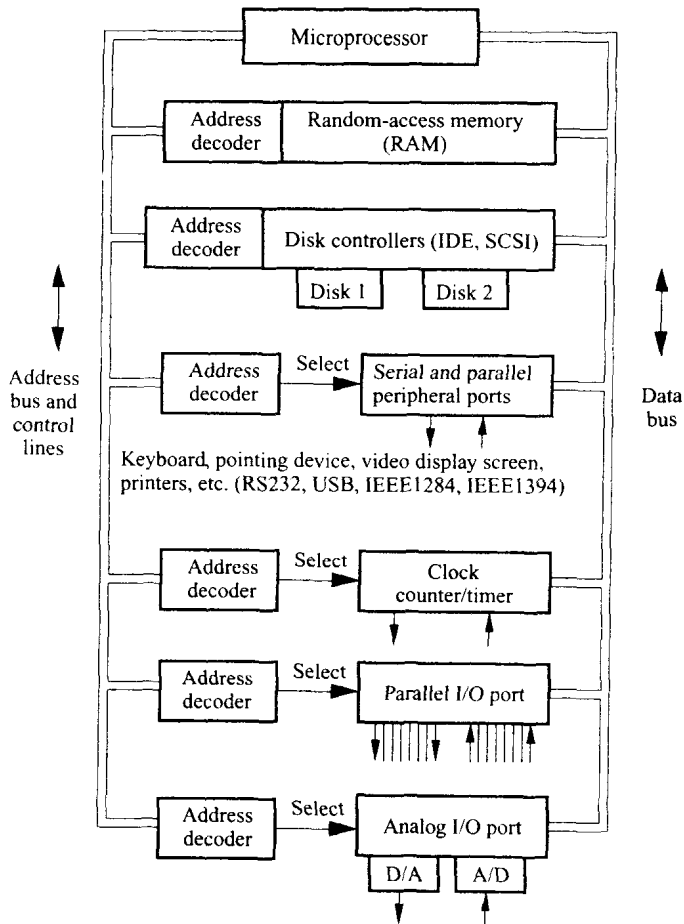
## 1.2 The microcomputer

In selecting a system for data acquisition and control, the **microcomputer** itself is a crucial component (Figure 1.2). The microcomputer is sufficiently small to fit on a laboratory bench (or desktop) and yet contains the following components:

1. The **microprocessor** is an integrated circuit that reads program instructions from memory and uses them to determine the sequence of actions that it performs. It is connected to memory and peripheral circuits by an address bus, a data bus, and control lines.

These actions include reading data and instructions from memory, performing calculations, executing different instructions depending on the outcome of a calculation, printing data, and transferring data to and from peripheral devices such as hard disks. Microprocessors vary greatly in their speed and data-handling capability.

2. **Random-access memory (RAM)** usually consists of high-speed semiconductor memory chips that are used to store and retrieve program instructions and data. The highest data-acquisition speeds are achieved when external data are read directly into RAM, so the size of the RAM places a limit on the number of data values that can be sampled rapidly.
3. Common user interface devices are the keyboard, video display screen, printer, mouse, joystick, and trackball. Some systems provide voice input and synthesized speech output. The IEEE-1284 interface standard includes the standard parallel printer (SPP) port as well as other enhancements. The universal serial bus (USB) is the current standard for keyboards and pointing devices. For higher



**Figure 1.2** The microcomputer consists of a microprocessor that communicates with memory and input/output devices by address and data buses.

speed transfers (external hard drives, digital camcorders, HDTV), the IEEE-1394 standard (FireWire or i.Link) has recently been introduced.

4. **Magnetic disk memory** is used for the long-term storage of programs and data, and consists of one or more flat circular plates coated with a magnetic surface. Magnetic disk capacities range from 500 kbytes to 2 Mbytes for small removable floppy disks and from 1 to 20 Gbytes or more for hard disks. Access time consists of a fixed delay of tens of milliseconds (for the read/write head to locate the desired track) and a transfer time of typically 1  $\mu$ s per 16-bit word.
5. **Optical disk memory** includes the CD-ROM and the DVD-ROM disks. The **CD-ROM** (compact disk-read-only memory) and **DVD-ROM** (digital versatile disk) drives use optical storage and retrieval technology that was developed for the music and entertainment industry. The capacity of the CD-ROM is over 600 Mbytes and about ten times larger for the DVD-ROM. Both are 12 cm in