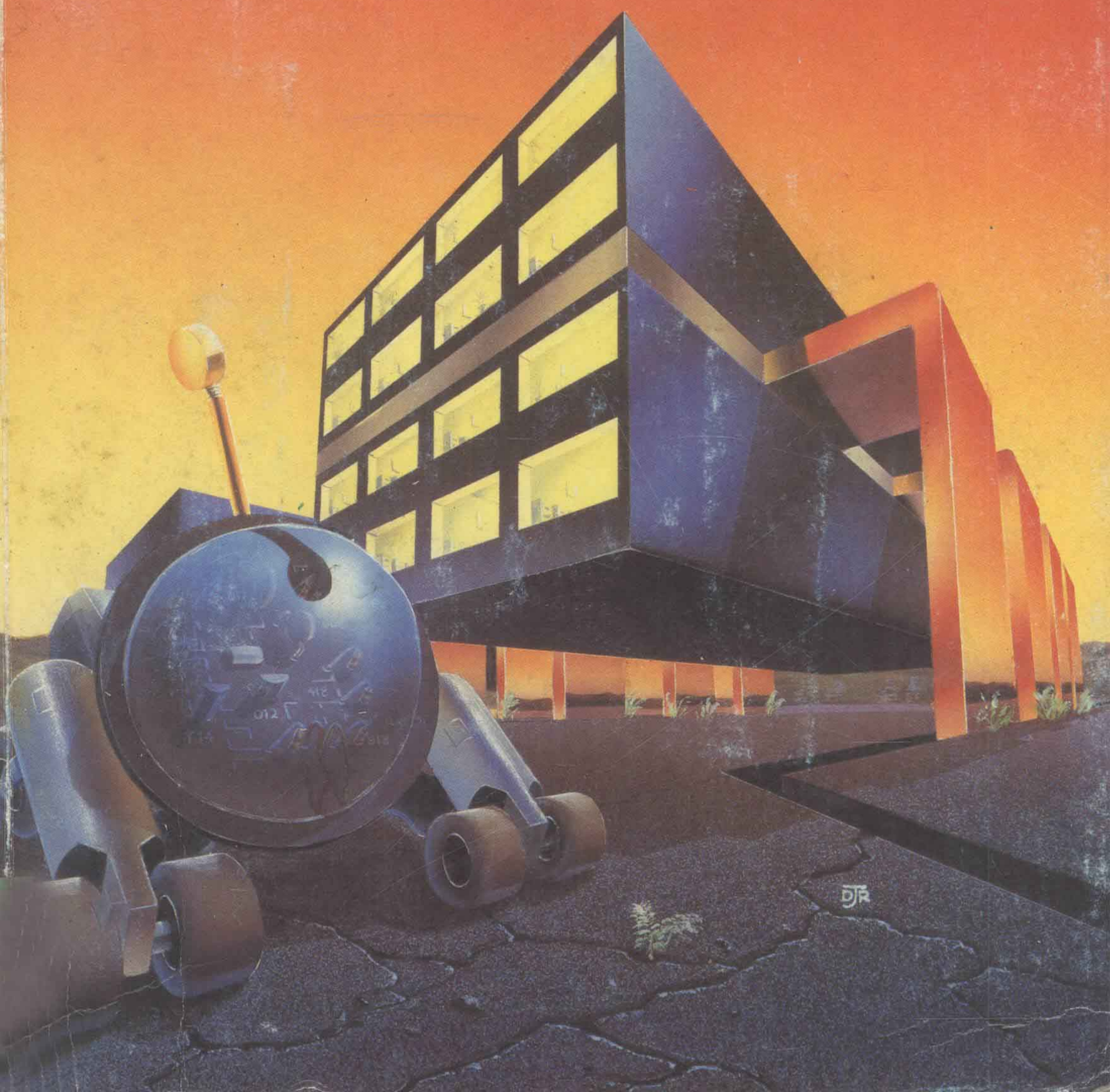
PRACTICAL INTERFACING

TO POPULAR MICROPROCESSORS

David Pritty
with Duncan Smeed and Peter Barrie



Practical Interfacing to Popular Microprocessors

David Pritty
with
Duncan Smeed and Peter Barrie

ADDISON-WESLEY PUBLISHING COMPANY

Wokingham, England · Reading, Massachusetts · Menlo Park, California
Don Mills, Ontario · Amsterdam · Sydney · Singapore · Tokyo
Mexico City · Bogota · Santiago · San Juan

The programs and circuit diagrams presented in this book have been included for their instructional value. They have been checked with care but are not guaranteed for any particular purpose. The publisher does not offer any warranties or representations, nor does it accept any liabilities with respect to the programs or circuit diagrams.

Cover design by David John Rowe
Typeset and Printed in Malta by Interprint Limited.

British Library Cataloguing in Publication Data
Pritty, David
Practical interfacing to popular microprocessors.
1. Microcomputers—Amateurs' manuals
I. Title II. Smeed, Duncan
III. Barrie, Peter
001.64'04 QA76.5

ISBN 0-201-14566-9

Library of Congress Cataloging in Publication Data
Pritty, David.
Practical interfacing to popular microprocessors.

Includes index.
1. Microcomputers—Amateurs' manuals. 2. Microprocessors—Amateurs' manuals.
I. Smeed, Duncan. II. Barrie, Peter. III. Title.
TK9969.P75 1985 001.64 84-16909
ISBN 0-201-14566-9

ABCDEF 898765

Practical Interfacing to Popular Microprocessors

To Agnes, Pauline, Susi, Alan, Iain, Heather and our Parents

Preface

The marvel of modern large-scale integrated circuit technology has changed the face of much of electronic system design over the last decade. In the past, electronic engineers used analogue or special-purpose digital computing elements hardwired together to solve a specific problem. Nowadays these problems are more conveniently and cheaply solved using programmable electronic systems, i.e. systems with a microprocessor control element at their heart. Here electrical signals are taken into the processor for analysis and computation and the results of these computations made to generate appropriate output signals. Such systems are widely used in industry, commerce and medicine and are variously referred to as process measurement and control systems, real-time control systems and automation systems.

Development and implementation of such systems has traditionally been the province of large industrial and commercial organizations. The advent of the personal microcomputer and the surrounding electronics industry infrastructure, able to manufacture and supply cheap components to private individuals, has brought the design and construction of such systems, albeit at a simple level, within the financial resources of the smallest companies and even the individual hobbyist.

The major impediment to wide exploitation is the lack of knowledge and skill. As such systems can involve knowledge in the fields of mechanical, electrical and electronic (both analogue and digital) engineering as well as computer science and physics, it is hardly surprising that specialist initiatives such as those launched by Government and the Universities to increase awareness of the power of microprocessor systems and information technology have been necessary.

Catering for this market thirsty for knowledge are a wide range of educational offerings ranging at one end from new University undergraduate courses in microprocessor systems and postgraduate conversion courses in Information Technology to a wide variety of computing and practical electronics magazines designed to inform and educate the general public.

The aim of this book is to fill the gap between the traditional textbook with its emphasis on academic theory and the magazine article which is rich in practical detail for one specific experiment or project but contains insufficient theory to allow the reader to develop general expertise which can be used to design systems of his own.

This book has been written specifically at the suggestion of participants on a six-week course in microprocessor control systems. The course was given to graduate engineers and scientists of a multinational manufacturing company, all of whom were from disciplines other than computer science and electronics. The course consisted of full-time lectures plus hands-on laboratory experiments of the type described in the book.

As a starting point, the book assumes a competence in BASIC programming and a passing acquaintance with assembly code programming and some general familiarity with the microcomputer world. An interest in electronics through a school club or otherwise will be helpful, although the book presents all necessary theory from the fundamental principles upwards.

The book covers many aspects of measurement, control and automation systems. There are chapters on the history of the subject, processor hardware fundamentals, logic design, integrated circuit technology and electronic construction methods, microprocessor interfacing, analogue signals, mechanical position control, system software, and complete systems development. An important feature is the inclusion of practical experiments which allow the reader to interface digital and analogue signals and produce mechanical movement from several personal microcomputers including the BBC, PET, Commodore 64, VIC 20, Apple and Dragon 32. Interfacing any other 6800 series and 6502 series microprocessor is covered in general terms.

The book adopts an integrated approach to the subject, building up the reader's understanding of basic logic design and electronic construction with only the theory necessary to allow practical interfacing to his own personal computer to take place. Once these simple experiments (which include an RS232 interface) have been performed, the more advanced aspects of logic design are introduced.

A major novel feature of the book is a modern approach to logic design theory which is relevant to the logic of programmable systems rather than the hardware systems they replace.

The explosion of interest in microcomputing has dramatically widened the range of people to whom the book will appeal. It is intended to appeal to anyone wishing to interface electronic signals to a microcomputer, including professional engineers in industry, University and Polytechnic students, and hobbyists. The general approach is to discuss the techniques involved at the fully professional level. However, the same basic principles are shown to apply to many more light-hearted uses such as control of model trains, racing cars and mobile robots. Examples of each of these are given both for the benefit of the hobbyists and also because these applications can provide considerable educational knowledge as well as being fun to implement.

January 1985 *David Pritty*

Warning!

Whilst every effort has been made to verify the accuracy of the information included in the book, neither the author nor the publishers can accept any responsibility in the event of any accidents or damage occurring to persons or equipment involved in undertaking these experiments.

Please always remember that mains electricity is dangerous and special care should be taken and professional advice sought when dealing with it. Also, please remember that your microcomputer could be damaged either by incorrect connections in your interface or by plugging and unplugging the interface with either the interface or the microcomputer switched on. For those microcomputers which do not have TTL buffering of their memory expansion buses, the effects of static electricity must be guarded against.

Practical details regarding tools and components for the experiments are given in Appendix 5.

Acknowledgements

The authors would like to thank the following: John Bradley and Gordon Winter for suggesting the book; colleagues in the Department of Computer Science at Strathclyde University for their help and support over the years, in particular, Jim McElroy and Ronnie Watson for constructing many of the systems that created the practical experience round which the book is based; and last, but by no means least, Jackie Burton, Christine Soutar and Jeanette Walsh who have typed our manuscript with great efficiency and patience.

The Publishers wish to thank the following for permission to reproduce material: Texas Instruments Inc; RS Components Limited; Apple Computer, Inc; and International Business Machines, Inc.

Contents

Chapter 1 From Analogue to Digital

1.1 A REVIEW OF THE DEVELOPMENT OF MICROPROCESSOR CONTROL SYSTEMS

The microchip will arguably go down in history as one of the most glamorous and popular scientific developments of the second half of the twentieth century. However, contrary to popular belief, it is not merely a modern-day phenomenon but a culmination of more than three centuries of imaginative thinking and dreaming by mathematicians, philosophers, engineers and eccentrics. The original dreams of automated thinking and calculating devices were given modest reality in the form of mechanical calculating engines by such persons as Leibniz and Pascal in the seventeenth century and later by Charles Babbage with his Difference Engine. However, these machines were not programmable in any sense, lacking memory and sequencing facilities.

Babbage's subsequent and more revolutionary Analytical Engine originated the concept of a device which might not only calculate but should do so in an ordered (programmable) fashion and might also act upon data represented in other than numeric form. Inspired by the operation of an industrial loom with 'programmed' patterns fed by cards, Babbage had a vision of a number machine with numbers weaving intricate and beautiful formulae. His machine was never realized, but dreams of music composing and game-playing machines were born and considered possibilities. The first ideas of Artificial Intelligence had occurred — before electricity!

The 1930s brought the arrival of the first stored-program machines, initially realized using electromechanical components and then using thousands of discrete thermionic valves as the logical and computing elements. These 'electronic brains' filled whole rooms and because of the low reliability of the valves were often more suitable as heating devices than providing serious computing facilities. However, although unreliable, these early machines created an environment for the creation of the new philosophy of computation and reasoning. These basic ideas are still used today in the cheaper, smaller and much more powerful computing devices available to everybody.

The evolution from the valve of the early 50s to the large scale integrated (LSI) and very large scale integrated (VLSI) chips of the 80s represent magnitude changes of the order of 10 000 times in terms of size, cost and probably reliability and power consumption. These electronic technology developments, which have taken place with a swiftness unprecedented in man's history, have resulted in huge expansion in all fields of electronic development. However, this expansion has probably been greatest in the area of digital computing which because of the nature of binary numbers and logic circuitry requires a large number of simple active devices to represent each quantity being processed.

Microprocessors, made possible by the new LSI chip technology of the late 60s, can be used as the heart of control systems, starting in the home with domestic equipment 'programmers' and ranging through hobby applications such as control of model electric trains, racing cars or music synthesizers to highly glamorous applications in industry and science such as inertial navigators for aircraft or inertial control systems for spacecraft. However, we must remember that, although the environmental conditions may be much more severe and the systems involve much more complex and time-critical computing, the control of a space craft and a model train involve the same basic principles. In this regard it is interesting to note that much of the large-scale integrated circuit technology which made the calculators and microprocessors of the 1970s (and hence the personal microcomputers of the 1980s) possible was initially developed for the United States space programmes of the 1960s.

The rate of technological development of active devices, i.e. devices that can amplify and switch electrical signals, has been particularly rapid over the last 30 years. In the 1950s passive circuit components such as resistors and capacitors were smaller, cheaper and much more reliable than valves and the objective of any electronic system design was to minimize the number of valves (i.e. active devices) used.

The large size and power consumption and low reliability of the valve made the digital computer a large static object which typically might fill a room. It was thus quite unsuitable for use in a moving vehicle such as an aircraft, where size, weight and power consumption have to be severely limited. Limited computing tasks were therefore undertaken using analogue computing techniques.

Because so many active devices are needed to implement even a small digital computer (a minicomputer as they were christened) it required the development of the small-scale integrated circuit (where several logic gates are included on the one chip) rather than just the discrete transistor itself before small digital computers could become competitive with analogue computing solutions. Using their own range of logic elements Ferranti produced just such a minicomputer for airborne use in the mid-60s. It was called the Argus 400.

During the 1960s, systems were built up using dedicated computing elements based on hardwired digital electronic counters, realized initially with valves and then with discrete transistors. As the electronic technology developed, integrated circuits were used in the hardwired electronics. Subsequently, minicomputers and then microprocessors replaced the hardwired systems.

This technological sequence was followed in most areas where the new digital technology was being applied; for with hardwired special-purpose digital solutions or analogue computing circuitry the volume of electronics is more or less linearly related to the complexity of the problem being solved, whereas with digital computing there is a fixed overhead in terms of the actual processing unit (nowadays the microprocessor chip) and the only variations tend to take place in the amount of store required to hold the programs and in the number of input/output circuits required. Thus, until the emergence of the microprocessor and LSI memory chips, the choice between special-purpose solutions using either digital or analogue techniques was fairly finely balanced. Normally, companies tended to use special-purpose computing techniques for simple systems and general-purpose minicomputers for their most complex systems in both the industrial and aerospace markets.

Discrete transistors and integrated circuits were first fabricated using a semiconductor technology known as bipolar, which is still in widespread use today. However, in the mid-60s an alternative technology emerged which, although slower, used less power and had the key advantage of allowing many more transistors per unit area of integrated circuit. This was known as MOS (metal oxide silicon) and further development and refining of the process was to provide the basis of implementation for the first large-scale integrated circuits — namely the electronic calculator chip, around 1970. A year later the American company, Intel, produced the world's first 4-bit microprocessor device, the 4004. This was quickly followed by two 8-bit devices, first the 8008 and then the greatly improved 8080. (Initial samples of the Intel 8080 were imported into the UK in 1974 at a cost of £250.)

The balance had now been irrevocably tipped in the direction of the general-purpose computer in the form of the microprocessor and the era of 'programmable electronics' had begun, i.e. the replacement of all hardwired electronic computing systems, both digital and analogue, with microprocessor and memory.

The decade that followed the advanced research work done in Intel's laboratories in the early 70s has seen microprocessors applied in a myriad of applications from spacecraft to home computers.

A corresponding increase in the availability of electronic components and drop in their prices has moved the whole microprocessor area out of the research laboratories and large industrial concerns into small business and the home. Now the technology is available for hobby or profit to any enthusiast who wishes to take the time and trouble to learn the principles and jargon of the subject.

We have reviewed some of the fields in which on-line real-time control systems (often called process measurement and control or automation systems) have been applied and the effect of technological developments on the way in which these systems were implemented. Section 1.2 describes the structure of such control systems at block diagram level.

1.2 PROCESS CONTROL SYSTEM STRUCTURE

General-purpose computing systems use standard peripherals for inputting, outputting and storing data (i.e. keyboards, VDU screens, printers, cassette tapes, floppy disks). The electrical signals produced by those peripherals are passed through interfaces designed by the computer manufacturer and translated into meaningful form by the computer's operating system. Thus the user, in general, need only concern himself with writing the program to solve his specific application. Usually the application program can be written in a high-level language (of which BASIC is one example). Software already exists within the machine to convert the high-level language program into the code obeyed by processor, i.e. machine code.

Personal microcomputers incorporate all the above facilities, albeit with limited sophistication.

In contrast to general-purpose computing applications where input data usually originates from a keyboard and outputs are available on a printer or VDU screen, the class of system we describe in this text is one whose primary function can be summarized as follows:

1) to receive electrical signals, perhaps representing some physical quantity or equipment status or other form of input data;
2) to interpret the meaning of the input signal (e.g. assign a value to the associated physical quantity);
3) to carry out computations on these input values;
4) to produce output electrical signals, e.g. to control machines or for display or data transmission purposes.

The computation function (3 above) is akin to computations involved in general-purpose computing apart from the additional constraints imposed in high-speed time-critical applications. However, we have in addition to undertake the analogue and digital electronic design involved in interfacing our input and output signals and to write the software necessary to convert these logical signals into meaningful form and pass their value to the general computational software.

Because such systems are usually required to control the operation of one piece of machinery or equipment they are described as dedicated systems, i.e. dedicated to a specific task.

Often the overheads of a general-purpose operating system are discarded and a small special-purpose operating system (called an executive) written to handle the configuration of input and output signals in the specific system.

Process control systems is the generic name applied to this class of systems. It refers to those systems used to automate plant or machinery and also other systems involving input and output of electrical signals which contain control or data information.

A generalized block diagram representing such a system is given in Fig. 1.1. This shows the main component parts in a process measurement and control (or automation) system.

As discussed above, our system is required to input electrical signals from sensors which measure the value of various input physical quantities (such as position, length, velocity, mass, force, strain, temperature and time) and convert them into digital form for use in the microprocessor. The electrical analogue or digital signals produced by the sensors or transducers are a reasonably *accurate* representation of the physical quantity being measured. Digital signals may require signal level changes, noise filtering and earth isolation before being fed into the microprocessor systems. Analogue signals require analogue-to-digital conversion as well as perhaps prior amplification, noise filtering and some earth isolation.

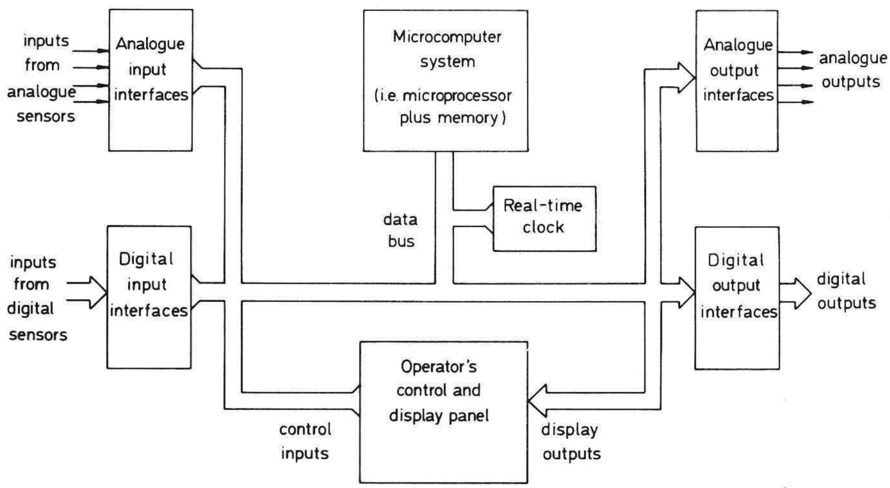


Fig. 1.1 Generalized control system — block diagram.

The converse operations are required on the output side. In addition to the measurement inputs and control outputs, the system may have several modes of operation. These can be controlled by a special operator's control panel which has a number of small control switches and buttons each dedicated to invoking a specific mode of operation. Systems often have minimal operator's display facilities, again to make the system easy to use and to reduce size and cost.

As much of the computing has to happen in real time and be able to be referred to real time, a real-time clock or timer is also included.

Now that we have described the overall configuration of a process control system in a generalized way, we shall proceed in the following chapters to describe the principles governing the operation of each of the component parts and their inter-relationship with each other. We go first to the heart of the system and describe the processor hardware fundamentals and then deal with interfacing to the processor buses. Later chapters deal with analogue signals and position control. The book concludes with a chapter on overall system design.