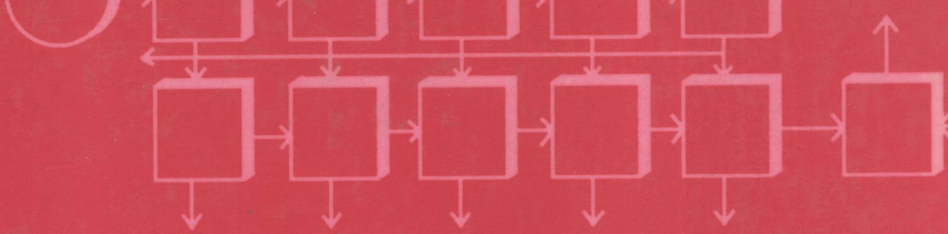

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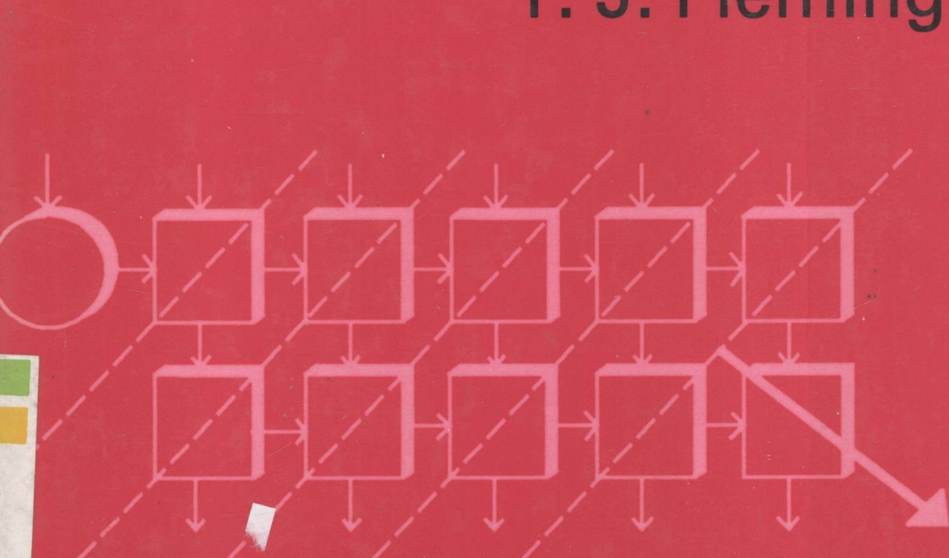

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Series Editor's Preface

It is a great pleasure to welcome the authors of the Chapters in this book to the Series in Industrial Control, Computers and Communications, and to thank the joint editors, Professors George Irwin and Peter Fleming, for their creativity in synthesising a book which demonstrates how transputers are being used in a wide range of real-time control applications. It is essential reading for all control and computer engineers.

The transputer is the only general purpose CPU that is currently in production in Europe. It was conceived as a transistor-computer that would contain, on one piece of silicon, the CPU, memory and I/O through the on-chip communication links; and therefore it provides a component for a scalable multiprocessor. Commercial products from European companies such as Parsys, Meiko, Parsytec and Quintek have utilised the transputer in their MIMD machines.

While such parallel computing machines have been well received, the worldwide revenue for all parallel computing machines is only of the order of £60 million at 1992 prices, which in worldwide computing values is the petty cash account! A general purpose CPU needs a mass market to generate the revenues to support the necessary future development that will take account of the improvements in silicon technology; at least ten million transistors per chip are predicted for 1995/96. The market for embedded systems and control is of crucial importance to the transputer. Consequently, a book on embedded real-time control is particularly timely and relevant. The authors have presented an exciting and stimulating range of applications, which clearly demonstrate the power and flexibility of the transputer in control.

The integration of computing has long been recognised as an essential feature of modern high performance equipment in which reliability, repeatability and safety are critical features. The complexity of many modern systems is now recognised as being beyond the capability of a human operator to control. There are many examples that can be cited to illustrate the fact that embedded control is an integral component of the total performance envelope - ranging from fly-by-wire in commercial aircraft as well as high-performance variable geometry, military aircraft to the stringent requirements of a nuclear power-station. The increase in embedded control in domestic equipment can be illustrated by the prediction that the cost of embedded control in a family car will increase in the next decade to 20% of the car's value. The particular examples chosen by the editors have brought together a comprehensive review of embedded control using the transputer. The book will prove a valuable and practical exposition of the subject for readers seeking to understand how they can implement transputer-based control systems, because commercial competition constantly demands that complex equipment meets the most stringent performance requirements, and that it is designed and delivered on time and within tight cost boundaries. This is particularly so in areas of the economy that have to react to the "peace dividend", in which new commercial challenges have to be surmounted.

There is a clear industrial and commercial need for expositions which show how new technology and techniques can be applied. The authors have satisfied this need and presented an excellent state-of-the-art review of a subject which is under continuous development.

Derek Wilson
London 1992

Preface

In some respects writing this preface has been the most pleasurable part of the whole exercise, not only because it represents the culmination of much hard work, but also because it provides an opportunity to look back and consider briefly the background of activity which led to this point.

Transputers are manufactured by Inmos Ltd, originally a UK government start-up company, now a member of SGS-Thompson Microelectronics NV. Inmos introduced the first member of the transputer family, the IMST414, in 1985. Since then the family has grown to include 16-bit and 32-bit processors, link adaptors and the C004 link switch. INMOS will soon bring to market the first members of a new series of transputer products, including the T9000 transputer and the C104 packet router. Embedded, distributed control applications were seen as an important market for the device right from the outset.

Our interest in the general area of parallel control grew alongside a series of events which were organised by the Institution of Electrical Engineers (IEE). The first Colloquium in the area of Control Engineering held in January 1987 was entitled, rather prophetically, "Parallel Processing - a New Direction for Control?". The success and obvious interest from both academia and industry prompted further Colloquia in 1988 and 1990 and the establishment of a series of Workshops in 1987-1989 on "Parallel Processing for Control - the Transputer and other Architectures". It is of satisfaction to note that these Workshops are now part of an IFAC series on

Algorithms and Architectures for Real-time Control (Bangor, UK 1991 and Seoul, Korea 1992).

The Science & Engineering Research Council/Department of Trade and Industry Initiative in Engineering Applications of Transputers has just been completed. The aim was to promote the development of transputer applications within the UK. As part of that process a Transputer Application Community Club in Real-time Control(CTACC) was established to co-ordinate and integrate both academic and industrial users of the new technology in the subject area of real-time control and some of the work described in this text initiated from that effort.

Given this background, and the imminent launch of the T9000 family, it is timely to produce a textbook which examines and reports on the use of transputers in real-time control across a spectrum of applications.

Our aim has been to showcase the potential of parallel processing for real-time control with the transputer as a unifying theme to provide a coherent and integrated text for the reader. The book will naturally be of use to control practitioners and researchers in the field. However, we have included an introductory Chapter to discuss more general issues associated with parallel processing for real-time control and to draw attention to the special features of this application area. It is anticipated that this will provide a useful pathway for newcomers to the subject.

In conclusion, we must pay tribute to the enthusiasm, energy and patience of our contributors and also thank our respective families for their support.

George Irwin
Belfast 1992

Peter Fleming
Sheffield 1992

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Contents

Chapter 1
Introduction

PJ Fleming and GW Irwin

1.1 PRELIMINARIES

The aim of this introductory Chapter is to place the contents of the Research Monograph in context, by reviewing briefly how real-time control has developed to its present state and also, importantly, to explain why the research described in the following Chapters constitutes an exciting and significant future direction for the subject. Automatic control techniques are applied right across the spectrum of engineering, including electrical, aeronautical, chemical, mechanical, environmental and medical. Consequently the variety and scale of examples of control systems is equally wide, e.g. fly-by-wire aircraft, power station boilers, robots, greenhouse environments, electricity generators, domestic heating systems, insulin pumps and video recorders.

Typically a control system must function at a number of levels. *Loop control* generally involves the use of negative feedback, perhaps with dynamic compensation to produce a fast, accurate, well damped response which is resistant to external disturbances and robust to changes in the system being controlled. *Sequential control* is concerned with producing the sequence of operations which a system should perform, such as the timed program on a domestic washing machine. *Supervisory control* ensures that the overall or global objective of the control system is being achieved. At one level this may consist simply of a condition monitoring function, for safety and fault detection. In a chemical plant it may involve fusing data from several sensors to detect faults and assist the operator to recover from an unforeseen situation.

Not surprisingly perhaps, advances in automatic control over the past four decades have been greatly enhanced by corresponding developments in electronics, particularly digital computer technology. Process control, as used in the chemical industry, provides a good illustration of this linkage. Thus, in the 1950's, early digital computers were expensive, cumbersome and unreliable and were only employed for plant monitoring and the supervisory control of existing loops. The first use of a digital computer directly within a feedback loop did not come until 1962 when a Ferranti Argus 200 machine was installed at an ICI ammonia-soda plant to measure 224 variables and manipulate 129 valves directly. Direct digital control had arrived. More recently, the 1970s and 1980s saw rapidly developing microprocessor technology being widely used in the implementation of small-scale and inexpensive digital controllers, as described later, and the growth of distributed control systems with a single master computer supervising a number of slaves.

It is worth mentioning that computer technology has also influenced and stimulated research effort on theoretical aspects, such as adaptive control. Thus the concept of a self-organising control system, where the control law adapts to accommodate significant plant changes and hence maintain performance, was first put forward by Kalman [1.1] in 1958. Building on earlier theoretical progress in system identification and stimulated by the potential of microprocessors, adaptive control schemes like self-tuning and model reference adaptive control [1.2] have been advanced and refined in recent years.

1.2 THE CHALLENGE OF REAL-TIME CONTROL

Let us now look more specifically at real-time digital control where, amongst other functions, the calculation of the controller output must be performed, within the loop