Robotic Control

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Robotic Control

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Series Editor's Foreword

The rapid development of electronics and its engineering applications ensures that new topics are always competing for a place in university and polytechnic courses. But it is often difficult for lecturers to find suitable books for recommendation to students, particularly when a topic is covered by a short lecture module, or as an 'option'.

Macmillan New Electronics offers introductions to advanced topics. The level is generally that of second and subsequent years of undergraduate courses in electronic and electrical engineering, computer science and physics. Some of the authors will paint with a broad brush; others will concentrate on a narrower topic, and cover it in greater detail. But in all cases the titles in the Series will provide a sound basis for further reading of the specialist literature, and an up-to-date appreciation of practical applications and likely trends.

The level, scope and approach of the Series should also appeal to practising engineers and scientists encountering an area of electronics for the first time, or needing a rapid and authoritative update.

Preface

Robots have already become standard tools for use in industrial automation systems, mainly where a variety of simple repetitive tasks is carried out. Their key feature, programmability, also allows their operation to be modified according to sensory information about their environment. Their surroundings may now be less well-defined, opening up new application areas and reducing the need for specially made jigs and fixtures. However, there is a long way to go before they can do useful tasks in completely unconstrained environments and before they have intelligence, instead of operating on explicit pre-programmed instructions. Once this has been achieved, the potential of robots will become enormous.

An initial study of robots would comprise an investigation into their mechanical construction, a survey of the types of sensors and actuators which might be used, and how control might be achieved so that the robot can perform the desired movements with the required speed and accuracy.

But practical robotics is much more than this. The robot must interface with its environment, in which there could be objects to be handled, feeding devices, other robots and people. A robot will usually be part of a larger system which can be programmed to perform a multitude of tasks. All of these items are considered here as being part of *Robotic Control*. The aim of this book is to present the concepts and technologies used in state-of-the-art robots, with an emphasis on fixed-base robots for industrial applications.

The early chapters describe the structure of a robot and its hardware components, followed by a study of how good dynamic control can be achieved. The programming aspects are considered in chapter 5.

The second part of the book develops the theme of adding external sensors and other equipment to the simple robot, making possible more advanced applications. Chapter 6 starts with an overview of typical external sensors and sensory data processing, and then looks at how this information may be used to enhance the capability of a robot. Workcell mechanisms such as feeders are described in chapter 7 which culminates in an illustrative example of the design of a sensory robotic workcell. Finally, chapter 8 attempts some crystal-ball gazing at future trends, based on reports of work being carried out at research institutes around the world.

The book is intended as a text for undergraduate courses or as an introduction for graduates new in the area. A basic working knowledge of computers and programming is assumed throughout, and of Laplace transforms in parts of chapters 3 and 4.

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All photographs are courtesy of the University of Hull unless noted below.

Figures 2.9, 2.10 and 2.13b courtesy GEC–Marconi Research Laboratories and Alvey 'Design to Product' project.

Figure 6.14 courtesy of the Department of Computer Science, University College of Wales, Aberystwyth.

Figure 7.7 courtesy of SATRA Footwear Technology Centre.

Contents

1 Introduction

Many people are fascinated by the operation of mechanical devices, particularly those which partially mimic human behaviour. This fascination seems to have been prevalent throughout the ages. It was common practice, for example, to adorn mediaeval clock mechanisms with mechanical figures which would seemingly parade and strike the bells as the clock reached the hour. Even today such mechanisms attract many sightseers. However, they are essentially only simple sequencing machines: the same series of events will take place time after time in a pre-determined and unalterable order.

Robots have the same fascination but the control needed for robots is far more extensive than that needed for simple sequencing machines. Not only will a certain sequence have to be carried out, but its operation must be insensitive to external disturbances and variations in the dynamic characteristics of the mechanisms. In this way the task can be repeatedly performed with the same precision. The framework for achieving this aim is provided by the study of automatic control.

In addition, the sequence of operations must be reprogrammable so that different tasks may be undertaken. It is the need to perform reliably and cheaply a wide variety of tasks that underlies the use of robots. As the task capability is paramount, we will take the term *robotic control* to cover not only the control of the mechanisms of the robot but also the associated sensory systems and other mechanisms needed to carry out the task.

1.1 Historical development

The concept of feedback lies at the heart of control engineering. The onset of the Industrial Revolution provided a potentially powerful means of driving machines — steam. However, it was also potentially very dangerous, exploding boilers and engines being not uncommon, and there was a great need for some way of automatically regulating the steam supply according to the load.

Sir James Watt's flyball governor, introduced in 1787, provided one solution to part of this problem. As shown in figure 1.1, if the load on the output shaft suddenly decreases the shaft will accelerate, causing the centrifugal forces to move the rotating balls outwards. This then raises the

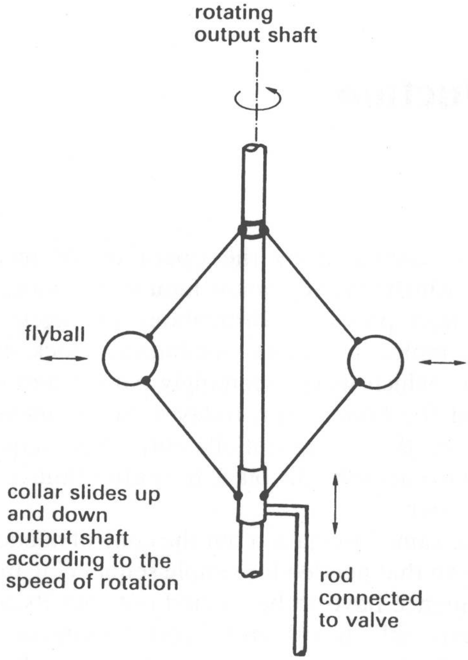

Figure 1.1 Watt's flyball governor

sliding member connected to the steam valve, thereby decreasing the steam supply and eventually reducing the output shaft speed. This principle was in fact in earlier use in windmills (Mayr, 1970) but the steam engine provided the first widespread application. A detailed treatment of the early history (up to 1930) of control engineering in general may be found in Benett (1979) and Mayr (1970), and of steam engines in particular in Dickinson (1963). As so often happens, it was only later that a theoretical analysis of the dynamics was attempted (Maxwell, 1868, reproduced in Bellman and Kalaba, 1964) once problems of unstable behaviour had arisen and required a solution.

The key development in the 1930s was the analysis (Nyquist, 1932) of stability in the new electronic amplifiers. An excellent collection of key papers on this and later developments in control theory has been assembled by MacFarlane (1979). This use of feedback was quickly applied to mechanical devices so that loads could be moved rapidly and accurately to pre-determined positions.

The industrial robot therefore embodies both the principle of sequencing and the use of feedback to provide accurate and fast movements. The reason why the emergence of robots is relatively recent lies in the evolution of fast, cheap and reliable computers which form the heart of the robot and provide both control and reprogrammability.

The availability of cheap computing has also meant a parallel development of sensors and sensory processing. This, with the inherent flexibility provided by having the robot's motions commandable from a controlling computer, means that the robot's movements can be modified according to the sensory information. If, for example, the position of a certain component is known only inexactly, a camera can be positioned over the component and a more exact position extracted from the camera data by a sensory processor. The position is transmitted to the robot which then picks up the component correctly. This is shown schematically in figure 1.2.

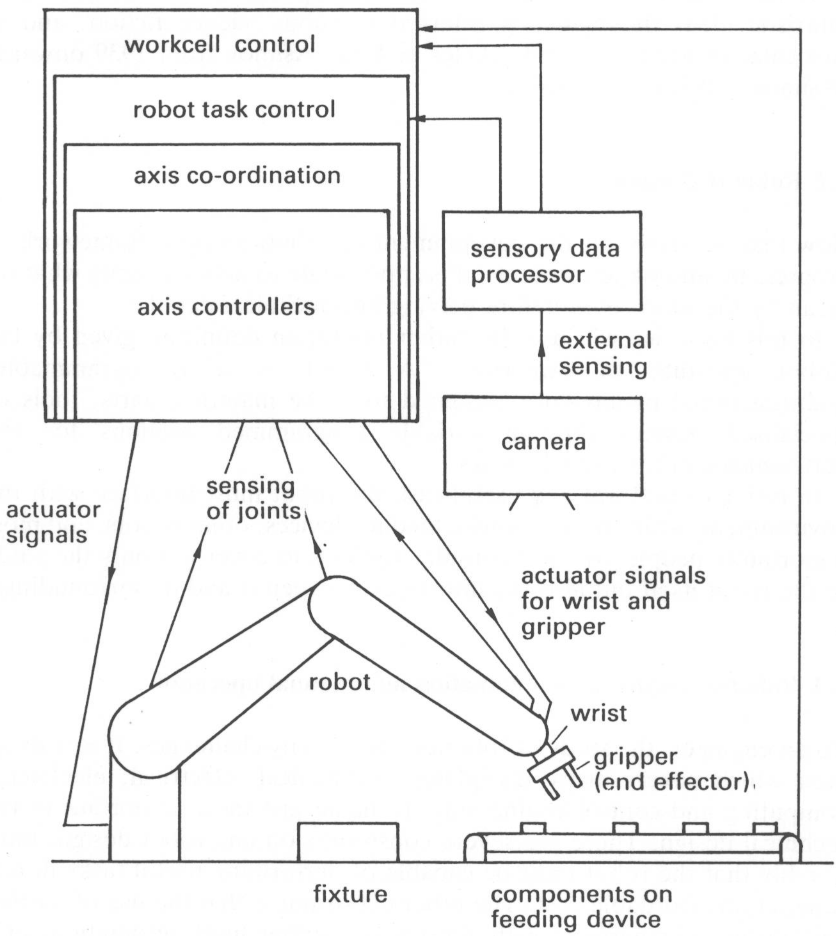

Figure 1.2 Schematic of a sensory robot system

If the camera is mounted on the end effector of the robot, it can continuously monitor the error between the component position and the end effector. This arrangement has several advantages over that shown in figure 1.2, as will be discussed in chapter 6.

However, although these machines are much more adaptable than either simple or reprogrammable sequence machines, their reactions to sensory feedback must be programmed explicitly. They will react to an error condition, in the above case a poorly positioned component, only if this has been foreseen by the programmer. Research workers are now studying the application of artificial intelligence techniques so that such explicit definition of error recovery actions is no longer necessary. The robot will have the intelligence to decide what it should do, or even what it should try to sense. This will form the limit of the scope of this book. For more futuristic ideas the reader is referred to robot science fiction, and in particular to the books and articles of Isaac Asimov from 1939 onwards (Asimov, 1983, for example).

1.2 Robot definition

Now that we have put the development of robotics into a framework of progress in automation systems, it is appropriate to define exactly what we mean by the term *robot* before delving into technical detail.

In this book we will use the rather utilitarian definition given by the Robot Institute of America: "A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialised devices through variable programmed motions for the performance of a variety of tasks."

In order to perform any useful task the robot must interface with the environment, which may comprise feeding devices, other robots, and most importantly people. We will consider robotics to cover not only the study of the robot itself but also the interfaces between it and its surroundings.

1.3 Robotics versus hard automation and manual operation

To an engineer, the study of robotics offers many challenges. It is truly an area which covers many disciplines: mechanical, electrical, electronic, computing and control engineering, to name just those important to the technical design. There are severe constraints on any robot design, most notably that the robot must be capable of performing useful tasks in real time, at an affordable cost. The other constraint is that the use of a robot will always be compared with alternatives, either hard automation, or a human.

Hard automation can be defined as the use of dedicated pieces of machinery, typically to produce the same item over long periods of time. This is expensive to build and inherently inflexible to product changes. However, its design can be optimised to produce the maximum amount of product at a minimum cost, so it is more attractive than the use of robots for the large-scale production of a few different items.

However, much of industry is concerned with batch production where perhaps one type of item is made during the morning and another during the afternoon. Human beings are very good in this environment. From a robotic point of view they are light, mobile structures with exceptionally good sensory perception and an intelligence far above that of any current robot. This gives them superb adaptability. However they tire, may become unreliable, unpredictable, and may well wish to be pursuing other activities which give greater scope for the use of their intelligence, or indeed just give greater pleasure.

A robot will neither be optimised for a particular application nor have the adaptability of the human. However, it can combine the reliability and predictability (at least until robots are made 'intelligent') of hard automation systems with a little of the adaptability of the human. Robots therefore have a place somewhere between these two extremes. For robots to play a positive part in supporting human activity, not only must they adequately perform a given task but the human aspects of any implementation must be thoroughly considered.

As stated by Rosenbrock (1979): "Any alternative technology should surely make better use of human abilities. It should not use men and women to perform meaningless, fragmented jobs which reduce them to automata. But this is not the same thing as suggesting a return to a more primitive craftsmanship, however satisfactory that may have been in its day. The problem is rather to use the best technology that we know, but to make it an aid to those who work with it, so that their work becomes an enrichment, not an impoverishment of their humanity, and so that the resource which their abilities represent is used to the highest degree."

Unfortunately there is insufficient space in this book to develop this and related economic factors.

In the justification of a robot installation, the easiest approach is to compare the local costs of the manual, robotic and hard-automation alternatives. But the values of any measures which are used will vary greatly according to the boundaries within which they are calculated. Let us assume that it is proposed that a particular subassembly operation is to be carried out by a robot instead of a person. If the boundary is drawn tightly round this particular operation, then the economic effects can be quantified in terms of production costs per unit, allowing for running costs, depreciation and overheads. If the complete product is brought inside the boundary, there may be increased cost benefits at later stages in the robotic assembly because our particular subassembly is better made. If the boundary is further widened to include field service, repairs and maintenance, more benefits may be seen to accrue. If the customer is considered, a better-made product may be safer, or give better customer satisfaction.

Let us now include the operator. The manual subassembly job may be of poor quality in terms of human job satisfaction and a better-quality occupation might be available elsewhere. The opposite, of course, may be true. Note that the term 'occupation' includes employment or leisure. If all of the factory employees are considered, then the measures might change markedly. The loss of a single job may preserve the survival of many others in an intensively competitive market. When the complete market, or the whole country, or the world, is included in the boundary then the measures change yet again.

In short, any economic measures of the viability of a robot installation depend on the standpoint and the field of view of the person making the judgements. It is important not to be too simplistic and narrow-visioned in one's approach to economic justification.

It is appropriate now to return to the more technical matters concerning robot installations — but the above factors should be borne in mind, particularly in the design of the workcell and the man–machine interface. First of all, we will take a quick look at the types of task which might be undertaken and then consider some possible performance measures which might be used to select or design a robot for each case. This will enable us to see in a broad sense the elements which will be required to make the overall system. These elements will then be studied in more detail in later chapters.

1.4 Application requirements

The key element about a robot which differentiates it from an automation system is its ability to be reprogrammed. This gives enormous potential flexibility so that the task being undertaken may be changed with perhaps only a small change in the robot's program. Most important, this flexibility can be used to cater for uncertainties in the environment, provided that appropriate sensory devices are connected and the information from them is used to modify the robot's behaviour accordingly.

From an applications point of view, it is convenient to split up tasks into three types for which different types of movement control are needed.