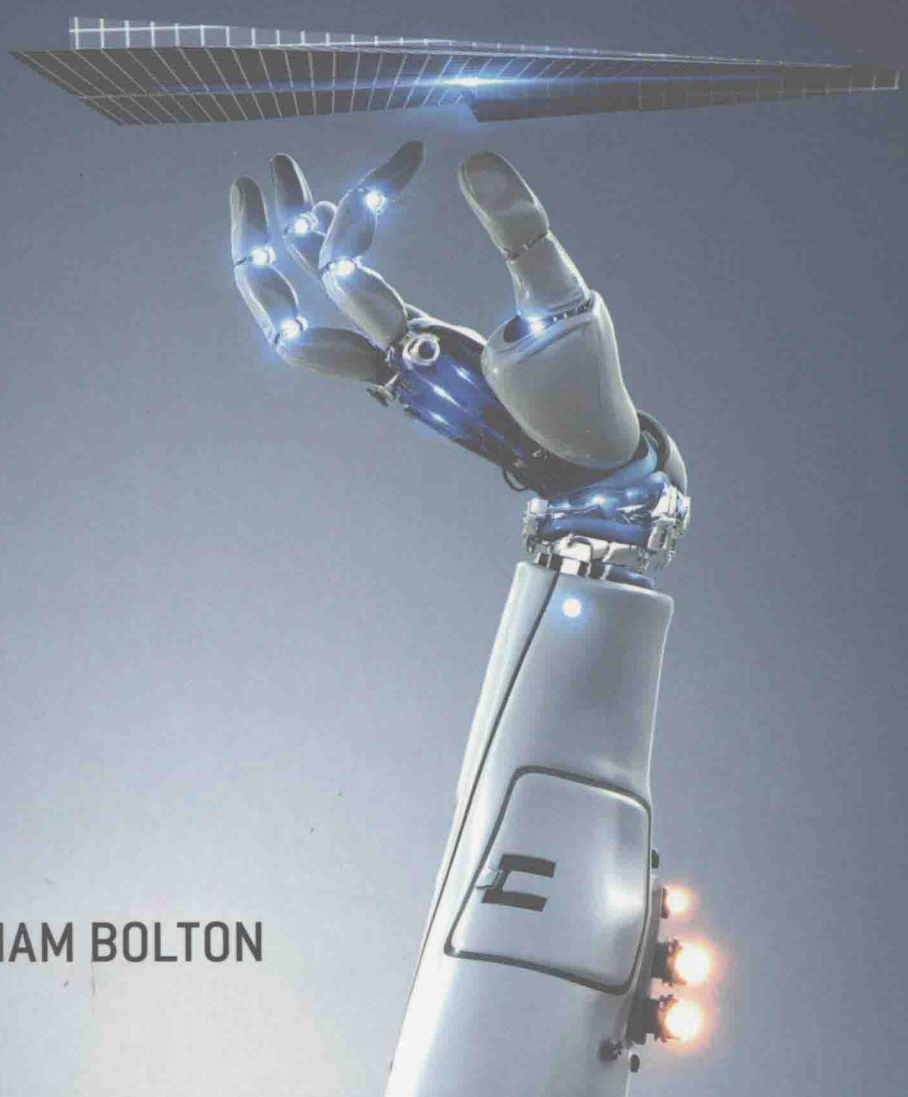
MECHATRONICS

ELECTRONIC CONTROL SYSTEMS IN MECHANICAL AND ELECTRICAL ENGINEERING

SIXTH EDITION



WILLIAM BOLTON

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MECHATRONICS

ELECTRONIC CONTROL SYSTEMS IN MECHANICAL AND ELECTRICAL ENGINEERING

Sixth Edition

William Bolton

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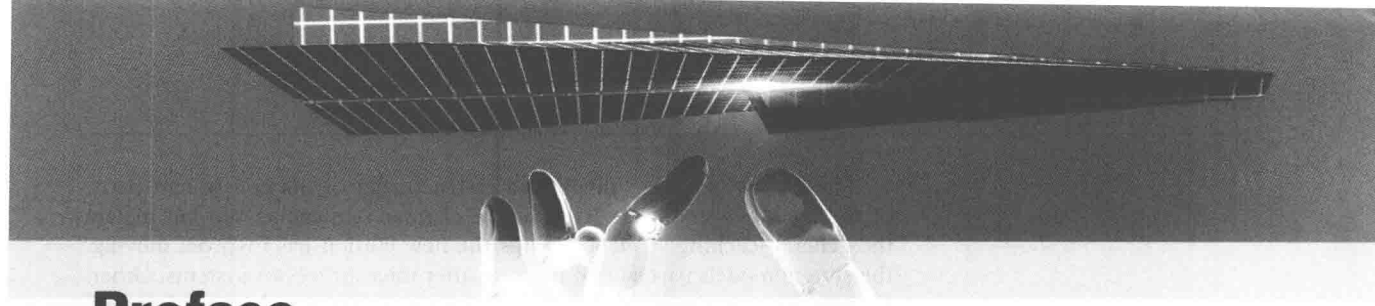

Preface

The term **mechatronics** was 'invented' by a Japanese engineer in 1969, as a combination of 'mecha' from mechanisms and 'tronics' from electronics. The word now has a wider meaning, being used to describe a philosophy in engineering technology in which there is a co-ordinated, and concurrently developed, integration of mechanical engineering with electronics and intelligent computer control in the design and manufacture of products and processes. As a result, many products which used to have mechanical functions have had many replaced with ones involving microprocessors. This has resulted in much greater flexibility, easier redesign and reprogramming, and the ability to carry out automated data collection and reporting.

A consequence of this approach is the need for engineers and technicians to adopt an interdisciplinary and integrated approach to engineering. Thus engineers and technicians need skills and knowledge that are not confined to a single subject area. They need to be capable of operating and communicating across a range of engineering disciplines and linking with those having more specialised skills. This book is an attempt to provide a basic background to mechatronics and provide links through to more specialised skills.

The first edition was designed to cover the Business and Technology Education Council (BTEC) Mechatronics units for Higher National Certificate/Diploma courses for technicians and designed to fit alongside more specialist units such as those for design, manufacture and maintenance determined by the application area of the course. The book was widely used for such courses and has also found use in undergraduate courses in both Britain and in the United States. Following feedback from lecturers in both Britain and the United States, the second edition was considerably extended and with its extra depth it was not only still relevant for its original readership but also suitable for undergraduate courses. The third edition involved refinements of some explanations, more discussion of microcontrollers and programming, increased use of models for mechatronics systems, and the grouping together of key facts in the Appendices. The fourth edition was a complete reconsideration of all aspects of the text, both layout and content, with some regrouping of topics, movement of more material into Appendices to avoid disrupting the flow of the text, new material – in particular an introduction to artificial intelligence, more case studies and a refinement of some topics to improve clarity. Also, objectives and key point summaries were included with each chapter. The fifth edition kept the same structure but, after consultation with many users of the book, many aspects had extra detail and refinement added.

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The sixth edition has involved a restructuring of the constituent parts of the book as some users felt that the chapter sequencing did not match the general teaching sequence. Thus the new edition has involved moving the system models part so that it comes after microprocessor systems. Other changes include the inclusion of material on Arduino and the addition of more topics in the Mechatronics Systems chapter.

The overall aim of the book is to give a comprehensive coverage of mechatronics which can be used with courses for both technicians and undergraduates in engineering and, hence, to help the reader:

- acquire a mix of skills in mechanical engineering, electronics and computing which is necessary if he/she is to be able to comprehend and design mechatronics systems;
- become capable of operating and communicating across the range of engineering disciplines necessary in mechatronics;
- be capable of designing mechatronic systems.

Each chapter of the book includes objectives, and a summary, is copiously illustrated and contains problems, answers to which are supplied at the end of the book. Chapter 24 comprises research and design assignments together with clues as to their possible answers.

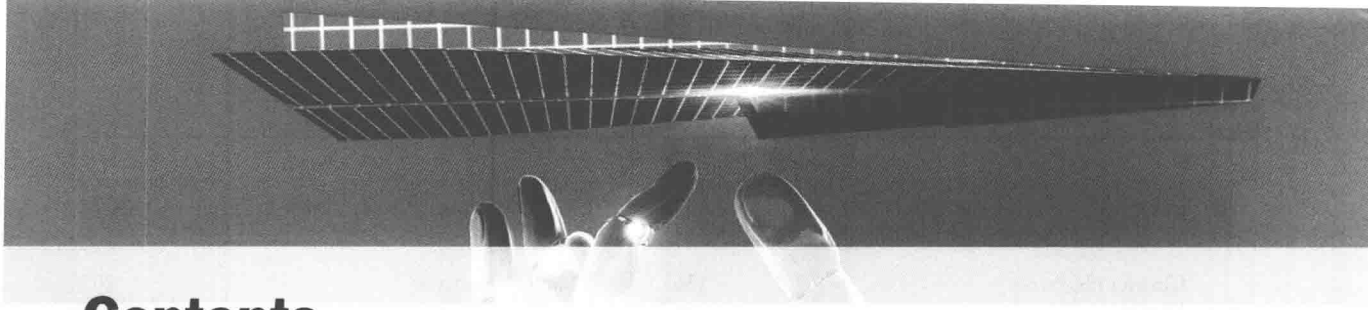
The structure of the book is:

- Chapter 1 is a general introduction to mechatronics;
- Chapters 2–6 form a coherent block on sensors and signal conditioning;
- Chapters 7–9 cover actuators;
- Chapters 10–16 discuss microprocessor/microcontroller systems;
- Chapters 17– 23 are concerned with system models;
- Chapter 24 provides an overall conclusion in considering the design of mechatronic systems.

An Instructor's Guide, test material and Powerpoint slides are available for lecturers to download at: www.pearsoned.co.uk/bolton

A large debt is owed to the publications of the manufacturers of the equipment referred to in the text. I would also like to thank those reviewers who painstakingly read through the fifth edition and made suggestions for improvements.

W. Bolton



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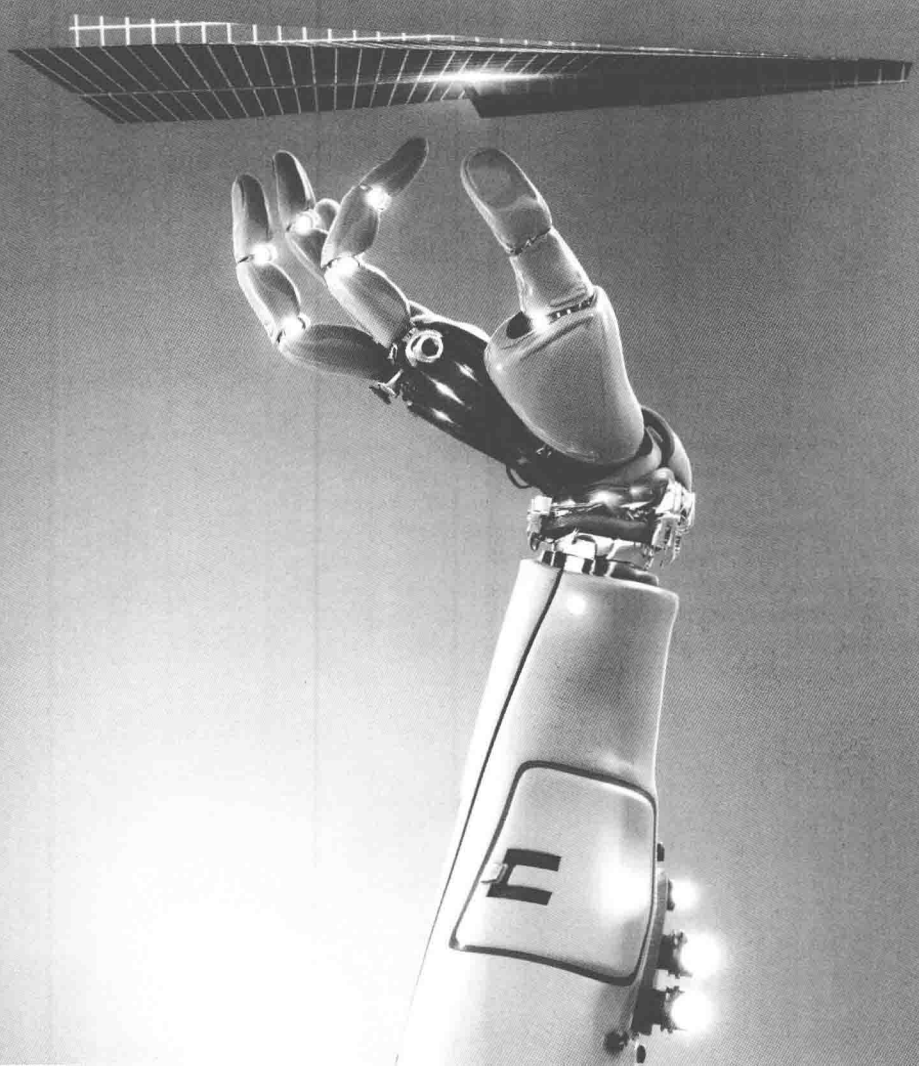
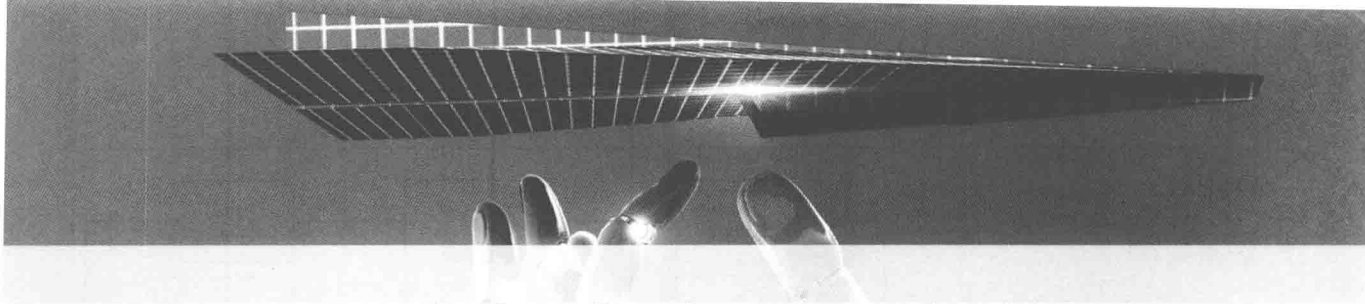
Part I
Introduction





Chapter one Introducing mechatronics

Objectives

The objectives of this chapter are that, after studying it, the reader should be able to:

- **Explain what is meant by mechatronics and appreciate its relevance in engineering design.**
- **Explain what is meant by a system and define the elements of measurement systems.**
- **Describe the various forms and elements of open-loop and closed-loop control systems.**
- **Recognise the need for models of systems in order to predict their behaviour.**

1.1 What is mechatronics?

The term **mechatronics** was 'invented' by a Japanese engineer in 1969, as a combination of 'mecha' from mechanisms and 'tronics' from electronics. The word now has a wider meaning, being used to describe a philosophy in engineering technology in which there is a co-ordinated, and concurrently developed, integration of mechanical engineering with electronics and intelligent computer control in the design and manufacture of products and processes. As a result, mechatronic products have many mechanical functions replaced with electronic ones. This results in much greater flexibility, easy redesign and reprogramming, and the ability to carry out automated data collection and reporting.

A mechatronic system is not just a marriage of electrical and mechanical systems and is more than just a control system; it is a complete integration of all of them in which there is a concurrent approach to the design. In the design of cars, robots, machine tools, washing machines, cameras and very many other machines, such an integrated and interdisciplinary approach to engineering design is increasingly being adopted. The integration across the traditional boundaries of mechanical engineering, electrical engineering, electronics and control engineering has to occur at the earliest stages of the design process if cheaper, more reliable, more flexible systems are to be developed. Mechatronics has to involve a concurrent approach to these disciplines rather than a sequential approach of developing, say, a mechanical system, then designing the electrical part and the microprocessor part. Thus mechatronics is a design philosophy, an integrating approach to engineering.

Mechatronics brings together areas of technology involving sensors and measurement systems, drive and actuation systems, and microprocessor systems (Figure 1.1), together with the analysis of the behaviour of systems and control systems. That essentially is a summary of this book. This chapter is an introduction to the topic, developing some of the basic concepts in order to give a framework for the rest of the book in which the details will be developed.

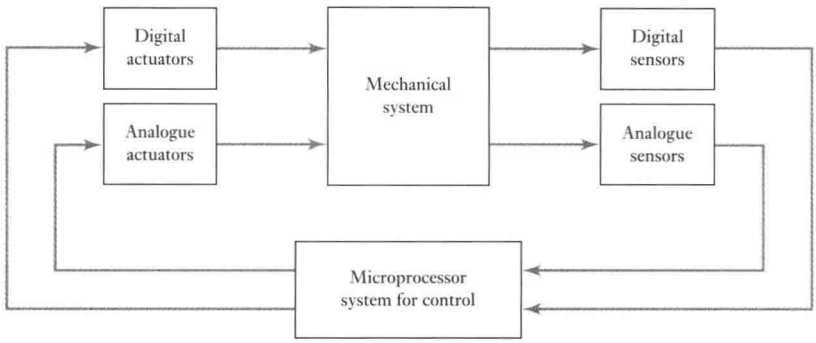


Figure 1.1 The basic elements of a mechatronic system.

1.1.1 Examples of mechatronic systems

Consider the modern autofocus, auto-exposure camera. To use the camera all you need to do is point it at the subject and press the button to take the picture. The camera can automatically adjust the focus so that the subject is in focus and automatically adjust the aperture and shutter speed so that the correct exposure is given. You do not have to manually adjust focusing and aperture or shutter speed controls. Consider a truck smart suspension. Such a suspension adjusts to uneven loading to maintain a level platform, adjusts to cornering, moving across rough ground, etc., to maintain a smooth ride. Consider an automated production line. Such a line may involve a number of production processes which are all automatically carried out in the correct sequence and in the correct way with a reporting of the outcomes at each stage in the process. The automatic camera, the truck suspension and the automatic production line are examples of a marriage between electronics, control systems and mechanical engineering.

1.1.2 Embedded systems

The term **embedded system** is used where microprocessors are embedded into systems and it is this type of system we are generally concerned with in mechatronics. A microprocessor may be considered as being essentially a collection of logic gates and memory elements that are not wired up as individual components but whose logical functions are implemented by means of software. As an illustration of what is meant by a logic gate, we might want an output if input A AND input B are both giving on signals. This could be implemented by what is termed an AND logic gate. An OR logic gate would give an output when either input A OR input B is on. A microprocessor is thus concerned with looking at inputs to see if they are on or off, processing the results of such an interrogation according to how it is programmed, and then giving outputs which are either on or off. See Chapter 10 for a more detailed discussion of microprocessors.

For a microprocessor to be used in a control system, it needs additional chips to give memory for data storage and for input/output ports to enable it to process signals from and to the outside world. **Microcontrollers** are microprocessors with these extra facilities all integrated together on a single chip.

An embedded system is a microprocessor-based system that is designed to control a range of functions and is not designed to be programmed by the end user in the same way that a computer is. Thus, with an embedded system, the user cannot change what the system does by adding or replacing software.

As an illustration of the use of microcontrollers in a control system, a modern washing machine will have a microprocessor-based control system to control the washing cycle, pumps, motor and water temperature. A modern car will have microprocessors controlling such functions as anti-lock brakes and engine management. Other examples of embedded systems are autofocus, auto-exposure cameras, camcorders, cell phones, DVD players, electronic card readers, photocopiers, printers, scanners, televisions and temperature controllers.

1.2 The design process

The design process for any system can be considered as involving a number of stages.

1 *The need*
The design process begins with a need from, perhaps, a customer or client. This may be identified by market research being used to establish the needs of potential customers.

2 *Analysis of the problem*
The first stage in developing a design is to find out the true nature of the problem, i.e. analysing it. This is an important stage in that not defining the problem accurately can lead to wasted time on designs that will not fulfil the need.

3 *Preparation of a specification*
Following the analysis, a specification of the requirements can be prepared. This will state the problem, any constraints placed on the solution, and the criteria which may be used to judge the quality of the design. In stating the problem, all the functions required of the design, together with any desirable features, should be specified. Thus there might be a statement of mass, dimensions, types and range of motion required, accuracy, input and output requirements of elements, interfaces, power requirements, operating environment, relevant standards and codes of practice, etc.

4 *Generation of possible solutions*
This is often termed the **conceptual stage**. Outline solutions are prepared which are worked out in sufficient detail to indicate the means of obtaining each of the required functions, e.g. approximate sizes, shapes, materials and costs. It also means finding out what has been done before for similar problems; there is no sense in reinventing the wheel.

5 *Selections of a suitable solution*
The various solutions are evaluated and the most suitable one selected. Evaluation will often involve the representation of a system by a model and then simulation to establish how it might react to inputs.

6 *Production of a detailed design*
The detail of the selected design has now to be worked out. This might require the production of prototypes or mock-ups in order to determine the optimum details of a design.

7 *Production of working drawings*
The selected design is then translated into working drawings, circuit diagrams, etc., so that the item can be made.

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