Mechatronics in Action
Mechatronics in Action

Case Studies in Mechatronics – Applications and Education
Foreword
The History of the Mechatronics Forum

Memiş Acar¹

Origins

The Mechatronics Forum came into existence at a meeting held at the Institution of Mechanical Engineer’s (IMechE) London headquarters on the 30th of October, 1990, and was attended by over 70 individuals. The Forum was the first organisation in the Western world to recognise the importance of mechatronics and to promote it as an integrating engineering discipline.

Although the word Mechatronics has been around since 1969 – the term was coined by Mr. Tetsuro Mori, a senior engineer of the Japanese company Yaskawa – it was only in the early 1990s that it began to be used to any great extent in the UK. However since then, through the activities of the Mechatronics Forum, the term mechatronics and the engineering design philosophy that it encompasses has become widely recognised.

Mechatronics today extends beyond the integration of mechanical, electronic and computer engineering. Many engineers now see it as embracing a wider range of engineering activities, from design through manufacture to the market place. Hence, they regard mechatronics as a major influence in pulling together and integrating the many aspects of engineering which increased specialisation has tended to push apart over recent years.

It was in an attempt to solve this increasingly difficult problem that the Mechatronics Forum was conceived as a first step towards the building of bridges between the many technologies, philosophies and disciplines which comprise mechatronics and the professional institutions that are committed to their own particular specialised subjects.

In this context, the Mechatronics Forum initially operated under a series of inter-institutional arrangements, with secretarial and administrative services provided alternately by the Institution of Mechanical Engineers (IMechE) and the Institution of Electrical Engineers² (IEE). However, in recent years, this

¹ Loughborough University, UK
² Now the Institution of Engineering and Technology (IET)
relationship has changed on a number of occasions and it currently operates under the auspices of the IMechE.

Mechatronics Forum Committee and Its Chairs

The founding Committee of the Mechatronics Forum was charged with a comprehensive portfolio of objectives including setting up and establishing a publication of a regular Newsletter, popularising mechatronics, focusing on educational issues, and seeking ways of bringing together all those interested in mechatronics, and especially of promoting closer links between industry and academia. These are still the objectives today, and significant advances have been made in relation to a number of them.

Today, the committee includes a number of members from outside the UK who help with the internationalisation of the Mechatronics Forum and its activities. To this end, the majority of its international biennial conferences have been held outside the UK.

The first Chair of the Mechatronics Forum was Professor Jack Dinsdale of the University of Dundee; the complete list of Chairs to the time of writing is:

<table>
<thead>
<tr>
<th>Year</th>
<th>Chair</th>
<th>Institution</th>
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<tbody>
<tr>
<td>1990</td>
<td>Professor Jack Dinsdale</td>
<td>University of Dundee</td>
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<tr>
<td>1993</td>
<td>Professor Jim Hewit</td>
<td>Loughborough University</td>
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<tr>
<td>1994</td>
<td>Professor Rob Parkin</td>
<td>De Montfort University</td>
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<tr>
<td>1995</td>
<td>Professor Tim King</td>
<td>The University of Birmingham</td>
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<td>1996</td>
<td>Professor Phil Moore</td>
<td>De Montfort University</td>
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<tr>
<td>1997</td>
<td>Dr Memis Acar</td>
<td>Loughborough University</td>
</tr>
<tr>
<td>1998</td>
<td>Dr Klaus Selke</td>
<td>University of Hull</td>
</tr>
<tr>
<td>2000</td>
<td>Dr Memis Acar</td>
<td>Loughborough University</td>
</tr>
<tr>
<td>2004</td>
<td>Professor Geoff Roberts</td>
<td>Coventry University</td>
</tr>
<tr>
<td>2008</td>
<td>Professor Phil Moore</td>
<td>De Montfort University</td>
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Mechatronics Forum Conferences

The Mechatronics Forum was the first professional group to organise conferences on this engineering field. The first conference was organised at Lancaster University in 1989 by Dr David Bradley who was, along with Prof. Jack Dinsdale and Prof. Jim Hewit, one of the three leading founders of the Mechatronics Forum. Although the Mechatronics Forum did not exist then as an organisation, the concept was in the minds of its founders at the time of the Lancaster conference. Hence, it is proper to count this conference as the first of the Mechatronics Forum Conferences.

This first conference was followed by conferences in Cambridge (1990) and Dundee (1992). After holding the first three conferences in the UK, in 1994 the Mechatronics Forum held its first conference outside the UK, organised in

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3 Now Prof. David Bradley and one of the editors of this book
collaboration with the Technical University of Budapest, Hungary. With this initiative, Prof. Jim Hewit played a pivotal role in the internationalisation of the Mechatronics Forum Conferences. All subsequent conferences have been held outside the UK. The following is the complete list of the biennial Mechatronics Forum Conferences to the time of writing:

1989 1st Conference  
**Mechatronics in Products and manufacturing**  
Lancaster University

1990 2nd Conference  
**Mechatronics – Designing Intelligent Machines**  
IMechE conference at Robinson College, Cambridge

1992 3rd Conference  
**Mechatronics – The Integration of Engineering Design**  
University of Dundee, Dundee, Scotland

1994 4th Conference  
**Mechatronics: the Basis for New Industrial Development**  
Technical University of Budapest, Budapest, Hungary

1996 5th Conference  
University of Minho, Minho, Portugal

1998 6th Conference  
University of Skövde, Skövde, Sweden

2000 7th Conference  
Georgia Institute of Technology, Atlanta, USA

2002 8th Conference  
University of Twente, Twente, The Netherlands

2004 9th Conference  
Middle East Technical University, Ankara, Turkey

2006 10th Conference  
Penn State University, Great Valley Campus, Malverne, USA

2008 11th Conference  
University of Limerick, Limerick, Ireland

2010 12th Conference  
ETH, Zurich, Switzerland

In addition, the Mechatronics Forum is organising the 10th International Workshop on Mechatronics Education and Research in (REM). This is a European network of universities active in mechatronics and the conference will be held in 2009 at the University of Strathclyde in Glasgow.

**Mechatronics Forum Prestige Lectures**

One of the principal activities of the Mechatronics Forum has been the organisation of a series of Prestige Lectures. The lectures in this series to the time of writing are:

1995 *The Role of Xero-Mechatronics in New Product Development*  
Dr John F Elter of the Xerox Corporation

1996 *Advances in Mechatronics: the Finnish Perspective*  
Vesa Salminan of FIMET

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4 Both the 1st and 2nd conferences were held before the Mechatronics Forum was formally constituted, but were instrumental in its establishment and hence are included in the list of conferences. After the Robinson College conference, it was agreed that subsequent conferences should come under the auspices of the Mechatronics Forum and be held biennially.
1997  *The Industrial Benefits of Mechatronics: the Dutch Experience*
Professor Job van Amerongen of the University of Twente

1998  *Virtual Worlds – Real Applications: Industrial and Commercial Developments in the UK*
Professor Bob Stone of the University of Birmingham,

2000  *Mechatronic Solutions for Industry*
Professor Rolf Isermann of the University of Darmstadt

2001  *Intelligent Mechatronics: Where to go?*
Professor Toshio Fukuda of Naga University

2003  *Bionics: New Human Engineered Therapeutic Approaches to Disorders of the Nervous System*
Professor Richard Normann of the University of Utah

2004  *GM's Approach to Eliminating Complexity and Making the Business More Successful*
Dr Jeffrey D Tew of General Motor’s R&D Center

2005  *Mechatronic Design Challenges in Space Robotics*
Dr Cock Heemskerk & Dr Marcel Ellenbroek of Dutch Space

2006  *Cyborg Intelligence: Linking Human and Machine Brains*
Professor Kevin Warwick of the University of Reading

2007  *Iterative Learning Control – From Hilbert Space to Robotics to Healthcare Engineering*
Professor Eric Rogers of the University of Southampton

2008  *World Water Speed Record Challenge – The Quicksilver Project*
Nigel Macknight, Team Leader and Driver, Quicksilver (WSR) Ltd

2009  *Meeting the Challenges and Opportunities of Sustainability Through Mechatronic Product Development*
Professor Tim McAloone of the Technical University of Denmark

**Mechatronics Forum Events**

The Mechatronics Forum also organises short one-day events on specific topics of interest for the benefit of its members. The following is a selection of the topics covered over the years:

1991  *Mechatronic Design for the Machining of Exotic Materials*
Seminar held at Leicester Polytechnic

1994  *Mechatronics – the Japanese Way*
Colloquium held at the IMechE in London

1995  *Innovative Actuators for Mechatronics Systems*
Colloquium held at the IEE Savoy Place in London

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5 Now De Montfort University
1996  *Mechatronics Education*
   Colloquium held at Manchester Metropolitan University

1996  *Mechatronics in Automated Handling*
   Royal Mail Technology Centre, Swindon

1996  *The Industrial Benefits of Mechatronics: The Scandinavian Experience*
   Colloquium held at the IEE headquarters at Savoy Place in London

1996  *Process Control and Robotics*
   IMechE in London

1997  *Mechatronic Systems*
   Workshop with Professor Rolf Isermann of Darmstadt University held at the IEE headquarters at Savoy Place in London

1997  *Intelligent Machines and Systems: the Implications for Mechanical Engineering*
   Workshop with Professor George Rzevski of the Open University held at the IMechE in London

1997  *Design of Modern Manufacturing Machinery*
   Colloquium held at the IMechE in London

1997  *Total Design of Mechatronics Systems*
   Workshop held at the University of Bath

1998  *Choosing and Using PLCs*
   Colloquium held at the IEE Savoy Place and the University of Birmingham

1998  *Learning from the Japanese Experience*
   Colloquium held at the IEE Savoy Place in London

1998  *Mechatronics Mini Symposium*
   Symposium at the IMechE Control 98 Conference at the University of Wales, Swansea

2002  *Future Trends in Robotics*
   Seminar at the IMechE in London

2003  *Mechatronics in Medicine*
   Symposium at Loughborough University

2008  *Robotics in Medicine*
   Symposium at the IMechE in London

**Mechatronics Forum Technical Visits**

Over the years, the Mechatronics Forum organised a number of technical visits to leading companies for its members. The following is a selection of some of the companies visited:

- Alcan (Bridgenorth)
- Analog Devices (Limerick)
- BAe Warton
- Brinton Carpets, Kidderminster
- British Aerospace (Brough)
- British Nuclear Fuels (Springfields)
British United Shoe Machinery (Leicester) Cirrus Technologies (Redditch)
Control Techniques (Newtown, Powys) Cranfield University CIM Institute
Cybernetics Institute, University of Salford Defense Research Agency (Chertsey)
Exitech (Oxford) FeONIC Plc, University of Hull
Flymo (County Durham) Ford (Dagenham)
IBM (Greenock) Komatsu (Redditch)
Lucas Advanced Engineering Centre (Shirley) Mars Confectionery (Slough)
Mitsubishi Technology Centre (Hatfield) Motorola (Easter-Inch, Edinburgh)
NCR (Dundee) National Oceanographic Centre (Southampton)
Pioneer Electronics (Castleford) Rank Taylor Hobson (Leicester)
Renishaw Metrology (Wotton-under-Edge) Rover Powertrain Division of Rover Cars Ltd.
Royal Mail Technology Centre (Swindon) Salford Advanced Robotics Research Centre
Siemens (Oxford) Magnet Technology University of Hull
Yamazaki Mazak Machine Tools (Worcester)

*Mechatronics Student of the Year Award*

The Mechatronic Forum also offers the Mechatronics Engineering Student of the Year Award, which has been specifically designed to help raise the profile of mechatronics design philosophy and mechatronics engineering education. The award provides a showcase for educational excellence by publicly recognising and rewarding the exceptional achievements of both students and universities. The competition is based around a submission of student's individual final year project report, or the group project report.

Entries are required to demonstrate:

- the application of mechatronics design philosophy to a specific engineering problem;
- an economically feasible solution in terms of its potential application in industry;
- excellent research and development practice, and final presentation.

The top three to five entrants are normally invited to the Finals where each student is required to present their project to the judges, who themselves are all engineers working in mechatronics.
Worldwide interest in *mechatronics* and its associated activities continue to grow annually. One indicator of this growth is the large number of mechatronics-based conferences on offer. When the first of what became the Mechatronics Forum conferences was organised in 1989, this was the only conference series which had mechatronics in its title. Searching the internet today reveals a myriad of national and international groups and organisations promoting mechatronics events.

As Memiş Acar says in his history of the Mechatronics Forum which appears as the Forward to this book, the word *mechatronics* is generally taken as having been coined in the early 1970s by Tetsuro Mori of the Yaskawa Electric Co. in Japan. Interestingly, from 1972 to 1982, *mechatronics* was a registered trademark of the Yaskawa Electric Co. It was not until the early 1980s that other organisations began to use the term in order to describe the philosophy of design teams.

Long before the word mechatronics came into general use it was recognised in industry that in order to facilitate innovation and increased efficiency in manufacturing and product design, it was vital for engineers and technicians from the disciplines of *mechanics* and *electronics* to work in synergy as teams rather than independently.

In my particular research area of marine systems, it is well known that the pioneering work of both Minorski [1] and Sperry [2] during the first quarter of the 20th century led to the development of automatic steering, or the ship steering autopilot. The evolution of the autopilot was itself made possible by the parallel development of powered rudders, or steering machines, and especially the electrically driven gyrocompass which overcame the problems associated with magnetic compasses which had their readings corrupted by local magnetic fields and the electrical systems in ships. Indeed, the invention of the electrically driven gyrocompass is arguably the most important breakthrough in ship control systems design, and its incorporation into the ship steering autopilot is probably one of the first examples of *mechatronics in action*.

The important legacy of Sperry and Minorski’s innovative work and their seminal publications is the three-term or proportional-integral-derivative (PID)
controller which continues to be the industry preference and standard for automatic control systems.

Whilst the above focuses on marine systems, it is evident that the mechatronics philosophy encompasses many disciplines and applications, a fact which is not only succinctly reinforced by David Bradley and David W. Russell’s introductory chapter to this book, but also by the range of topics presented in the accompanying chapters. John Millbanks’s chapter covering the interrelationship of mechatronics and sustainability is a timely reminder that the mechatronics philosophy in more than simply ensuring the initial product design is right; it is equally applicable for whole life/cradle-to-grave considerations. Other important and key applications of mechatronics in action which are at the leading edge of technological developments pertain to road, rail and air transportation systems, i.e., fly-by-wire, steer-by-wire, brake-by-wire, tilting trains, aircraft and space vehicles, where embedded microprocessor systems facilitate and augment the necessary interface between electrical and mechanical components and subsystems.

The book also contains two chapters which address mechatronics education, an area that is often popular and well-attended at sessions at the Mechatronics Forum and other conferences. It is pleasing to see that mechatronics courses at pre-degree, degree and post graduate levels offered by universities in Europe, the Far East and America are on the increase, but disappointing that in the United Kingdom, mechatronics courses have not been as popular as would be expected. This is the case despite the UK industry’s well-publicised requirements for engineers and technicians who are well-versed in both electrical and mechanical engineering.

A solution to this is for bodies such as the Mechatronics Forum to continue to promote the mechatronics philosophy through its conferences, seminars lectures and books. I therefore commend the authors for producing this extremely informative combination of topics, which taken together, demonstrate the importance of mechatronics and the significant impact that mechatronics in action has on our daily lives.

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Chapter 1
Introduction

David Bradley¹ and David W. Russell²

1.1 Background

Since 1989, the Mechatronic Forum conferences have provided practitioners and educators working in the field of mechatronics with the opportunity to meet and discuss not only technical developments, but also aspects of course design and delivery. As mechatronics has developed as a subject, and as more and more students are exposed to the underlying concepts through courses at undergraduate and master’s levels [1–3], there is an increasing requirement to provide both students and practitioners with access to examples of functioning systems in order to reinforce the concepts and structures which underpin the mechatronic concept.

This book essentially arose from discussions at the Mechatronics Forum conferences, and in particular at Penn State Great Valley in 2006 where the education workshops made it clear that despite the growth in the number and availability of mechatronic textbooks, there was a need for something which drew attention to issues associated with and impacting on the design and implementation of mechatronic systems rather than the underlying technologies.

The aim of the book is therefore to provide, through the medium of case studies by leading practitioners in the field, an insight for all interested in the mechatronic concept and the ways in which mechatronic systems and the associated educational programmes are designed, developed and implemented [4–7].

1.2 What Is Mechatronics?

As a discipline, mechatronics is faced with the problem that though it has the evolutionary path suggested by Figure 1.1, it does not represent a single technological domain, but rather the integration of a number of such domains at

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¹ University of Abertay Dundee, UK
² Penn State Great Valley, USA
the systems level. This means that there is no single, clear and agreed upon
definition of mechatronics around which practitioners and educators can align
themselves and develop courses and programmes. Indeed, as John Millbank, one
of the contributing authors has commented [8]:

   By definition then, mechatronics is not a subject, science or technology *per se* – it is
   instead to be regarded as a philosophy – a fundamental way of looking at and doing
   things, and by its very nature requires a unified approach to its delivery.

   This perspective is illustrated in part by Figure 1.2 which places mechatronics
   at the centre of a network of engineering functions ranging from aesthetics to
   marketing. In reviewing this network it is, however, important to recognise and
   understand that mechatronics is not solely about technology but relies on people,
   and in particular on the interaction between individuals to make it work.

   ![Figure 1.1 The evolution of mechatronics [9–12]](image1)

   ![Figure 1.2 Mechatronics and some of its related domains](image2)
Mechatronics can therefore be considered as being, in essence, a systems approach to the design, development and implementation of complex engineering systems which takes as its foundation the transfer of functionality from the physical domain to the information domain. The strength of the approach is that it supports the understanding of the nature of the embedded complexity by ensuring that the different engineering and other disciplines are considered together from the start of the design process. A mechatronic approach to system design and development therefore has much in common with the Concurrent Engineering model of Figure 1.3 in that it emphasises parallelism and implies an integrated path from concept to implementation in which there is a balance between all activities within the design process.

This parallelism is important as new products traditionally generate the most revenue early in their life cycles, particularly if the products offer new features not present in their competitor’s products. As the product matures and competitors enter the market, profit erosion will begin to occur as the competition for available customers increases. It is therefore important that products are designed and produced on time, and that production rates are rapidly ramped up to mature levels. Any delays in the release of the product to the market will translate into lost sales that will not be recovered over the life of the product.

![Fig. 1.3 Concurrent engineering work flow](image-url)

As indicated by Figure 1.4 [13, 14], a key element of this profile is the need to convince the pragmatists that the system is of value to them once the innovators and early adopters have opened up the market. The introduction of a mechatronic approach to technology integration allied to a concurrent engineering development strategy has resulted in products which are inherently more capable, and hence more attractive to users than their predecessors at reducing real costs.
1.2.1 Mechatronics and Design Innovation

In recent years, products and systems of all types from domestic appliances to vehicles have become increasingly complex. This complexity is in turn defined by the combination of local and distributed processing power with mechanical design, and is driven by the increased availability of such processing power allied to enhanced communications strategies and protocols. Thus, at one level a system such as the Wii games console [15] utilises three-axis accelerometers to record motion and to translate that motion into an on-screen response by means of a Bluetooth [16] communications link. At another level, a modern car will integrate multiple systems ranging from engine management to environmental controls for driver and passenger comfort, and potentially even autonomous navigation [17].

These developments are supported by the increasing availability of ‘smart components’ such as the SunSPOT4 system from Sun Microsystems [18], which in turn facilitate the construction of larger systems utilising the embedded processing power of their distributed elements. The increasing availability of system elements

3 Courtesy of the University of Utah
4 Sun Small Programmable Object Technology
such as SunSPOTs and RFID tags is resulting in increasingly complex systems in which the ability to analyse and interpret the data then becomes the major source of added value.

While mechatronics has been historically associated with system products such as vehicles and manufacturing technologies such as robots, these same mechatronic concepts are now appearing in applications such as healthcare. Considering this latter area in more detail, developments in prosthetics are resulting in artificial limbs of increasing capability. These ultimately have the potential to be linked to a neural interface such as that of Figure 1.5 [19], making them capable of decoding nerve impulses and returning a feedback signal to the user to achieve more realistic control than is currently possible.

In physiotherapy, the development of systems such as MANUS [20, 21], Locomat [22] and NeXOS [23] aim to support physiotherapists working with a wide range of individuals and conditions. At the systems level, the development of telecare systems based on a distributed network of sensors to monitor individual behaviour within their home environment to support independent living is attracting increasing interest, particularly when combined with advanced analysis techniques to interpret such behaviour [24, 25].

### 1.2.2 Mechatronics and Manufacturing

Engineers from most disciplines will quite understandably associate mechatronics with robotics and factory systems. Systems that move, machine and assemble “hard” substances are really only classifiable as ‘mechatronic’ to the degree that they contain elements of reasoning and agility. A flipper paddle on a production line barely counts as a robot! As manufacturing systems have evolved across the world despite the plentiful labour supply, the inclusion of virtually unattended automation components is growing. Areas of mechatronic involvement in manufacturing include assembly, machining, inspection, dangerous material handling and disassembly.

The modern automobile contains many of the same technologies, including all-wheel drive and electronically-actuated fuel injection. Since the inception of the production line illustrated in Figure 1.6 [26, 27], automobile assembly plants have led the way in robotic painting, welding and heavy material handling.
With the introduction of the ‘make to order’ paradigm, manufacturing is now far more sophisticated than simply mass producing items for inventory. Buyers now want to customise everything and to do so at almost the unit level. This has necessitated an agility of operations that was previously unimagined. Manufacturing groups can now be created [28] ‘on-the-fly’ in response to job specifications, which may involve autonomous work-cells moving into varying positions as part of a dynamic collaboration. In addition to containing many degrees of freedom, each manufacturing cell may also be multi-faceted and provide a variety of job functions on a piece by piece basis. For example, a unit that is customarily used as a gripper to move completed work-pieces from assembly to a conveyor may also from time to time insert a component, and all within the same production run.

Because of the combinational complexity of such systems, the scheduling of flexible architecture work groups has attracted the interest of methodologies that include game theory [29] and self-organisation [30, 31]. The problems associated with flexible groupings are manifold. Any operation that involves autonomous vehicular movement must allow for unobtrusive inactive parking, dynamic path and scene analysis, unit return and recovery strategy, and self reporting of malfunctions and maintenance intervals. All of these are commonplace mechatronic system issues.

The pharmaceutical and power generation industries are also heavily dependent on mechatronic devices to provide skilled operations in environments where it is either unsafe or inconvenient for humans to work. This includes the handling of toxic and radioactive materials and maintenance in heavily polluted atmospheric conditions. Automated inspection systems provide 100% quality control and dramatically outperform humans in such boring and repetitive tasks.

While mechatronic systems are an obvious area of interesting research, they are also gaining acceptance and popularity in manufacturing processes and are becoming an integral part of a greener and more sustainable industrial world. Along these lines, there is a current trend to design commodity items such as cell phones for disassembly and component reuse. Manufacturers are usually concerned with securely fastening units together, which consequently makes for
safer use but condemns the product to the landfill. By careful design for remanufacturing, it will become economically feasible as well as environmentally prudent to produce goods that are truly recyclable with no loss in quality. Mechatronics will feature heavily in this arena!

1.2.3 Mechatronics and Education

In the development of mechatronics education, the concern in course design has always been that of achieving an appropriate balance between providing the necessary depth of understanding of core technologies and the ability to develop solutions which integrate those technologies. This may be compared with a subject based approach to engineering education where the emphasis is on ensuring a depth of understanding within the subject area.

The education of a mechatronics engineer thus has to place a greater emphasis on the ability to work across and between individual areas of technology. This is not, however, to suggest that a mechatronics engineer does not have to have a depth of knowledge in certain specialist areas, rather that such depth is balanced by an understanding and appreciation of the contributions of other areas of technology as is suggested by Figure 1.7.

![Fig. 1.7 Balance of technical expertise for specialist and mechatronics educated engineers: (a) specialist education, and (b) mechatronics education](image)

The achievement of a balanced programme of mechatronics education must therefore ensure that individuals are provided with sufficient depth in at least one area of technology in order to allow them to make an effective contribution to that area, whilst ensuring the breadth of understanding necessary to give them credibility in regard to other subject specialists. The key challenge then facing mechatronics course designers is that of ensuring that there is an appropriate balance between depth and breadth within the course, as well as providing opportunities to enable students to practice integration.
Though mechatronics emphasises integration, it may also be perceived as encompassing a number of themes such as design, manufacturing or automation. In relation to course development, the choice of theme is generally dictated by a number of factors including:

- the backgrounds and interests of the staff involved in teaching;
- industrial requirements, both locally and nationally;
- student perceptions and interests;
- availability of resources, particularly human and financial;
- research activity.

While it is unlikely that any one of these considerations will dominate course development to the exclusion of others, any one of these factors may well be the defining influence for a particular programme or course. Generally, however, they will all play some role in determining the structure of any course.

For instance, resource implications will often mean that teaching of specialist material will require that mechatronic engineers are incorporated as part of a larger group of subject specialists for this purpose, with the courses then being structured to meet the needs of the subject specialists rather than the mechatronics students. Also, the increasing modularisation of programmes can tend to mitigate against the ability to introduce the necessary integrating material, particularly where modules are seen as having to be complete and entire within themselves.

In light of the above challenges, how might the designers of a mechatronics course respond? What is clear is that they are faced with a number of questions including:

- Should a theme be chosen or should it emerge as a result of the local expertise and enthusiasms?
- How are the integration aspects of mechatronics to be introduced and managed?
- How are external requirements, as for instance the Bologna Agreement in Europe [32, 33], to be managed?
- What is the local market for graduates, and is the proposed course going to meet those requirements?

Mechatronics has always suffered to some degree from an identity crisis both within the academic community and elsewhere, and indeed this is likely to continue to be the case given the diversity of approaches and emphasis that are found within the community. At the same time, there is a need for graduate engineers with the particular integration skills that are provided by a mechatronics education. The challenge facing mechatronics course designers is therefore that of achieving an effective balance between the requirements for detailed knowledge and engendering of the ability to act in an integrating role in a wide range of engineering environments.

The achievement of this balance is itself subject to a whole range of pressures ranging from the rapid advance of technology to external factors impacting on
course management and design such as the moves to implement sustainable systems or increase student mobility. The underlying precepts presented here will, however, remain as a constant for course designers and developers.

1.3 Mechatronics and a Sustainable Future

It is clear that the future development of mechatronics will need to be integrated with the need to meet and respond to a range of challenges in areas including energy systems, transport, health care, medicine and manufacturing. Indeed, it can be argued that the achievement of sustainable systems in these and other areas will depend on the ability to integrate a mechatronic approach to system design and development into corresponding developments in areas such as materials technology. This will impact not only on specific products, but on the ways they are made.

This will in turn cause present considerations of design for manufacture and assembly which are often in conflict with the requirements of design for disassembly or maintenance to be brought into question. Consider, for instance, the use of snap assembly methods for joining components. These are easy to assemble but can make access problematic without the destruction of the item in question.

1.3.1 Sustainability

In the 1987 report of the Brundtland Commission, *Our Common Future*, sustainable development was defined as [34]:

> Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.⁵

In the UK, the Department of Trade and Industry has stated that [35]:

> Sustainable development is about achieving economic growth, environmental protection and social progress at the same time.

The paper *A Way with Waste* from the Department of the Environment, Food and Rural Affairs (DEFRA) states that [36]:

> Sustainable waste management means using material resources efficiently to cut down on the amount of waste we produce. And where waste is produced, dealing with it in a way that actively contributes to the economic, social and environmental goals of sustainable development.

⁵ Formerly the World Commission on Environment and Development and chaired by the then Prime Minister of Norway, Gro Harlem Brundtland
There is increasing recognition of the importance of environmental sustainability to industry, as reflected in a number of indices that have been developed to try to express levels of sustainability in product development. This is reflected in legislation which seeks to control the environmental impact of products through the regulation and control of their disposal and the management of the associated waste materials.

Within the EU, some of these key legislative elements introduced, or in the process of being introduced are [37]:

- waste from electrical and electronic equipment [38];
- restriction of the use of certain hazardous substances in electrical and electronic equipment [39];
- end of life vehicles [40];
- packaging and packaging waste [41].

Other legislation seeks to control the production of pollutants such as greenhouse gases, as for instance the EU Emissions Trading Scheme which came into being on January 1, 2005 [42, 43]. This brings about the possibility of trading in ‘pollution certificates’, such as the Clean Development Method certification under the auspices of the United Nations Framework Convention on Climate Change (UNFCC) [44–46].

All of the above lead to an increasing recognition that there is a requirement to adopt a more holistic approach to the design and use of a wide range of products and systems, and that whole life considerations need to be taken into account as part of the design process [47–49]. This has lead to the concept of Life Cycle Assessment and the ISO 14040 [50] series of standards which sets out 4 key elements for consideration, namely:

- goal and scope definition;
- impact assessment;
- inventory of extractions & emissions;
- interpretation.

Despite the considerations above, however, it cannot be said that environmentally friendly strategies and approaches to whole life cycle design have been widely adopted. Indeed, in his keynote address to the ICED03 conference, Dr Tim McAloone of the Technical University of Denmark commented that:

There are now a number of centres of excellence in EcoDesign practice, both in industry and academia, where tools and methods have crystallised into positive changes to the environmental performance of the product under development. However, there are even more instances where the tools and methods developed fail to be integrated into real life product development, due to shortcomings of either academia or industry whilst developing the tools, or when attempting their integration.

There is indeed a range of activity worldwide with subjects under investigation including [51–55]:
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- environmental sustainability;
- EcoDesign;
- EcoDesign tools;
- design for sustainability;
- environmental technology;
- lifecycle assessment;
- environmentally conscious manufacturing;
- environmentally friendly product design;
- environmentally friendly products.

Industry has taken the lead in some of these areas as for instance in the work undertaken in Germany by the Verein der Automobilindustrie [56] (VDA) and through the Blue Angel programme [57]. In Italy, Fiat instituted the FARE (Fiat Auto Recycling) programme [58] in 1992, which by 1997 had 251 recycling centres while in Sweden. Volvo has developed their EPI (Environmental Product Information) system [59] as a means of informing users as to the environmental impact of their cars. Similar strategies have been followed by many other car manufacturers. In other areas, companies such as Dell [60] and HP [61] have instituted major environmental management programmes in association with their product range.

There have also been attempts to develop tools to support environmentally friendly design, the best known of which is probably that of Boothroyd & Dewhurst that uses the MET (Materials, Energy, Toxicity) points system developed by TNO in Holland [62].

1.3.2 Mechatronics and Sustainability

As suggested, mechatronics should have a considerable role in achieving sustainable products and systems. Some of the potential areas where mechatronics is likely to have a major impact are outlined below and some will be considered in more detail in subsequent chapters.

Design

In relation to developments mechatronics and the design process, approaches such as EcoDesign⁶ encompass a wide range of issues which will impact upon the general mechatronic concept, particularly the means of achieving sustainable outcomes in ways which support trade-offs between system elements. Thus, the adoption of a manufacturing process which has associated with it slightly increased levels of waste may support actions elsewhere in the product lifecycle which lead to an overall reduction in waste production.

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⁶ Also Green Design, Sustainable Design and Environmentally Friendly Design, etc.
Transport

This is likely to be an area where mechatronics will significantly influence design, development and operation. For instance:

Rail – The further development of tilting trains, active suspensions, driven and steered wheelsets and traction and braking control are all likely to feature to some degree in future train systems, along with enhanced drive technologies and controller strategies [63]. Other potential areas of development include high-speed trains and the use of maglev technologies [64, 65].

Road Transport – The move towards hybrid vehicles and the use of fuel cell technology [66, 67] as well as on-board systems for driver assistance and management support a wide range of potential developments. Developments at the vehicle level would then be supplemented and supported by enhanced traffic management and routing systems that would look at route loading and capacity to optimise journey times and minimise pollution.

Aircraft – Aircraft, the growth of air transport and the impact on the environment is undoubtedly one of the most contentious areas in which mechatronics is likely to play a role. Issues include the design of aircraft that are quieter, more fuel efficient and have a lower environmental impact than those currently in use [68–71].

This shift is seen with the introduction of the Airbus A380 and the Boeing 787 Dreamliner. More radical developments and concepts include the ‘blended wing’ [72, 73] and enhanced engine technologies.

Energy Technologies

The deployment and use of alternative energy sources such as wind and wave power [74, 75], the introduction into the home of micro combined heat and power (microCHP) systems [76], heat pumps [77] and fuel cells as well as new generations of appliances and energy management options within the home will all be influenced by mechatronic approaches to their design, operation and control.

Manufacturing

Mechatronics will continue to support the development of advanced manufacturing systems involving autonomously reconfigurable machine tools [78] and dynamic decision making [79] as an integral part of the process. Such developments will in turn support the implementation of production facilities that are more energy efficient and have lower environmental impact than those currently in use.