

Chapter 2

Mechatronics Disrupted

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2.1 How It Started

The field of mechatronics started in the 1970s when mechanical systems needed more accurate controlled motions. This forced both industry and academia to explore sensors, and electronic assisted feedback, while using mostly electrical drives instead of, for instance, mechanical cam shafts in production facilities. This introduction of feedback-controlled motion formed the basis for the need to enable mechanical engineers and electronic engineers to work better together and to understand each others language. Note that in those days control engineering departments were mostly part of the electrical development or research departments of industry and academia. Various initiatives were also undertaken to develop a common language or methodology. Some institutes pushed mechatronics forward as being a new discipline.

In industry, the design teams were typically forced to really discuss at the specification level deeper insights from within their specific disciplinary knowledge. Computer-assisted design and simulation tools really boosted the field in the late 1980s and 1990. An example of the project-oriented mechatronics way of working has been the development of optical storage devices such as that of Fig. 2.1 [1]. Teams of mechanical designers, using their finite element programs, and electronics and control specialists, with their specific simulation tools, codeveloped mechanisms with very tight specifications on manufacturability, cost and dynamics.

In that same time frame of the 1980s, in many industries and academia, mechanical engineers started more and more to also address dynamics and control, and control groups started to emerge also in mechanical engineering departments, all of which signalled a move away from the mono-disciplinary approaches of Fig. 2.2 [1].

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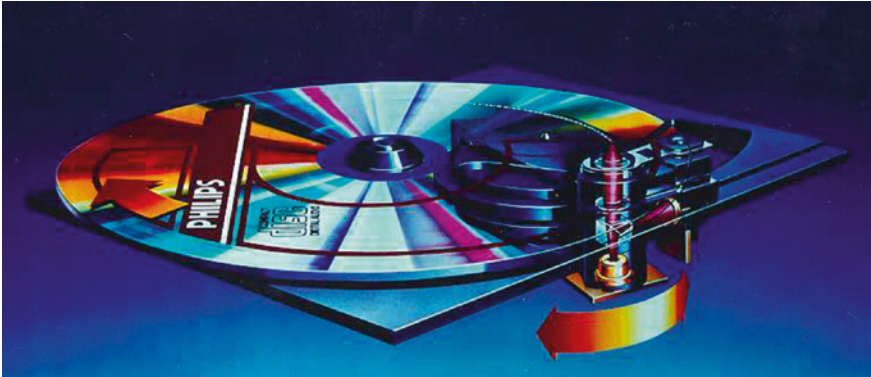


Fig. 2.1 An optical storage device with a balanced rotating arm by philips electronics NV

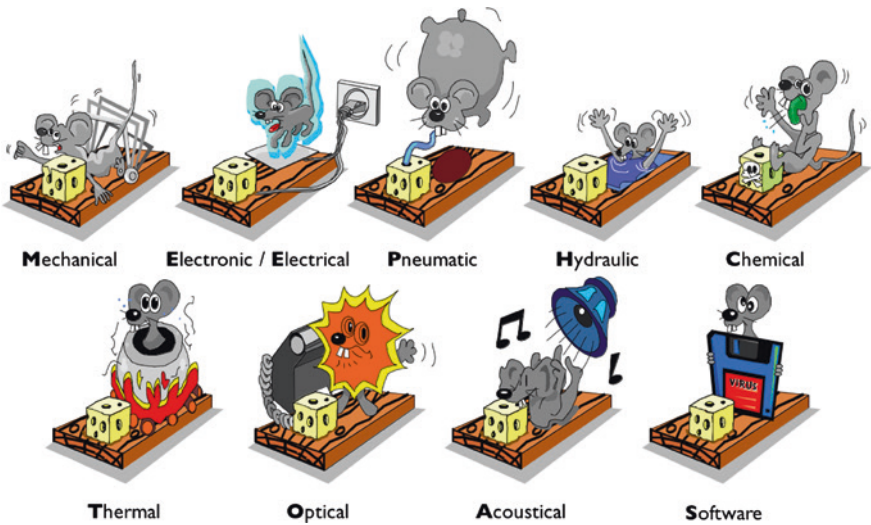


Fig. 2.2 Many mono-disciplinary solutions for a given problem [1]

2.2 Computer Controlled Devices

The rapid development of the personal computer, enabled the better use of simulation and design tools, and hence improving the overall design process and quality of exchange of design ideas in an early phase. However, and equally relevant, the PC-enabled digitized computer controlled mechatronic systems testing and implementation. This required addressing the role of computer science engineering and showed the need to include the software discipline, but to a still rather limited extent. This also led to include more and more the field of systems engineering as

a way of working in industry on more complex products and high tech systems. However, thinking about the ‘common’ language, or at least to understand each other better, clearly is far less trivial between the hardware and software domains, than within the hardware domain itself.

From a research perspective, the questions start at the discrete time level, i.e. how to use the computer to implement control functions such that the performance previously done with analogue implementation was maintained as much as possible. However, soon the higher level supervisory control modes were taken into the mechatronics field, and this forced research to make the switch towards the much more difficult questions of discrete event systems, facing continuous time dynamics in the mechanical system. This has led to the research field of hybrid systems within the systems and control discipline. This part forms the natural interface between the hardware (the ‘old’ mechatronics) and the software (computer science) field.

2.3 Applications

The performance improvements due to mechatronic thinking have been profound and are broadly acknowledged. Applications of mechatronics can be found in many products and production environments. Although in the early days, the control of electric motors was an often seen application, mechatronic thinking also is used in the design of hydraulic systems, piezo driving actuators, the modelling and control of production equipment, scientific equipment, opto-mechatronics, automotive mechatronics, etc.

Overseeing the inflow of submitted mechatronics papers over the last few years, more application papers are submitted on medical devices, on high precision systems, drones (UAV), automotive and robotics. The papers on scientific achievements on modelling languages and tools have reduced, meaning probably that appropriate tooling is now more common. The same seems to be true for papers on education in mechatronics. This was a hot topic in the late 1990s, where good examples were found including experimental work for the students.

There are not so many discussion papers anymore about what could be called the mechatronic design method, because it is by now maybe clear that part of the innovation done in mechatronics in practice has more to do with helping disciplines to communicate, preferably via the use of shared models or quantified simulations. The scientific methods addressed in mechatronic journal submission are mostly seen in the systems and control area, where the mechatronic application is often used as a validation or simply as a show case. An emerging field is the use of optimisation algorithms, not only for finding optimal control laws, but more and more also for component design, up to system topology optimisation as a new design tool [2]. The core of the mechatronic submissions and community still is Mechanical Engineering, Electrical Engineering and the area of Systems and Control. The interrelation with Computer Science and Physics is still rather limited, but this is going to shift to coming years.

2.4 Multi-physics

High-end mechatronic systems such as wafer scanners such as that of Fig. 2.3 for optical lithography or electron scanning probes and in space applications and scientific instrumentation, have an error budget that is getting closer to being a flat distribution over the various sources.

For instance, for modern wafer scanners thermal and cooling-fluids-induced vibrations now are as significant as mechanical modal vibrations excited by the actuators. This has to do with the extreme conditions and requirements; moving an 80 kg mass with accelerations more than 10 g, and achieving accuracies below nanometres with mKelvin temperature variation [3]. This means that the ‘normal’ mechatronics and its motion control systems now start to have a dynamic interaction with the thermal and fluid control dynamics. The overall performance assessment and design improvements now start to cover not only mechanical and electrical/electronic and software disciplines, but also physics issues like thermal and fluid partial differential equation-based modelling. And what will be the impact for mechatronics design thinking when we include the possibilities of additive manufacturing? If a 3D industrial metal or ceramics printer can be used to freely shape our mechanisms, how to arrive at an overall optimal design?

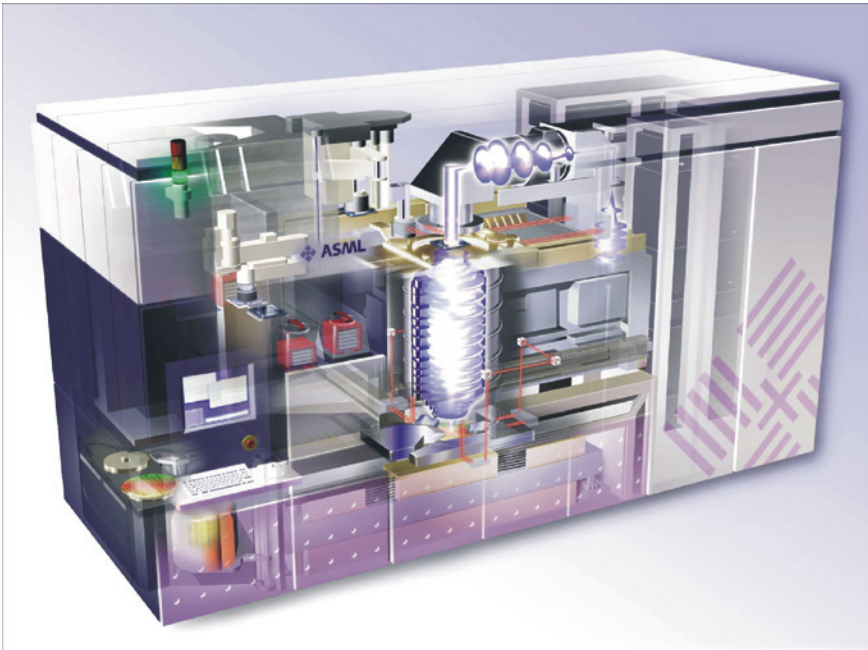
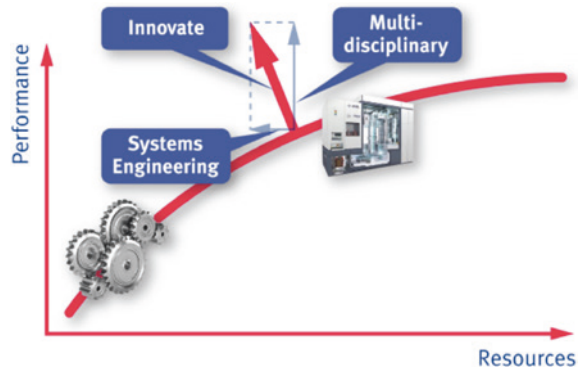


Fig. 2.3 Wafer scanner

Fig. 2.4 The performance complexity (resources) trade-off [4]



The performance trade-off can now only be lifted to the next level if we are able to handle this complexity by proper systems engineering and the inclusion of more disciplines.

In Fig. 2.4 this trend is depicted in the form of a performance versus resources plot. Resources could be money, people, development time, computer power, energy, etc. The performance typically is accuracy, throughput and robustness/reliability. The curve shows that achieving more performance does cost more and more resources, until not feasible. In the figure, examples are also plotted; first, a simple transmission gear system, having low performance (in terms of accuracy) and also requiring limited resources. The second, example in the figure is a modern wafer scanner as the example of extreme performance and needing huge resources.

The curve implies that in order to further boost innovation, we need to incorporate two means. First, by addressing all relevant disciplines, so including for instance physics, we will be able to increase performance. Second, by introducing a systems engineering approach we can handle complexity in a better way, and hence, go left on the resources axis.

2.5 Robotics

Almost opposite to the high-end systems as described above, the robotics field also influences the mechatronics area. Here, it is not the multi-physics discipline that is required, but the computer science field to cope with unstructured and changing environments. In robotics, the developments are directed towards vision, mapping, and localization, so understanding the environment (*'world modelling'*) but also the field of Artificial Intelligence (AI)—which has already been a promise for decades, but could evolve rapidly in coming years. Both areas are currently in an accelerating phase because of the upcoming autonomous vehicles. The disruption seen in the automotive industry is huge, both in the area of power trains



Fig. 2.5 The *Preceyes* eye surgery robot [5]

(i.e. electric drives and transmissions), and the use of computer science, as for instance the sensors in a modern car, including the rapid developments in autonomous functions implemented in passenger cars as well as in commercial vehicles. This in fact is all about mechatronics, AI, controls!

The field of robotics, including autonomous cars, could be treated as a separate research area, next to mechatronics, but for instance the speed requirements of industrial robots or the accuracy requirements of surgical robots such as the *Preceyes* robot of Fig. 2.5 necessitate the inclusion of the description of the dynamic behaviour of the robots. The change from rigid body modelling towards flexible systems, then directly makes it in the heart of mechatronics. The same holds for the systems engineering thinking and the system topology optimization, which is also similar in hybrid power trains for vehicles. So where does mechatronics end and robotics start?

2.6 Cyber-Physical Systems, Smart Industry and the Internet of Things

The shift from decentralized mechatronic systems towards networked connected systems is known as the field of cyber physical systems, referring to the field of cybernetics. The research questions are how to guarantee stability

and performance during or after packet (information) loss, and how to deal with variable delays. The domain is even further away from the hardware of mechatronics, but is developing so rapidly, that we should ask the question how to embrace to potential of network-controlled systems, for instance in the field of remote condition monitoring and servicing. In the next decade, the explosion of the Internet of Things (IoT) further necessitates finding the answers to this question [6].

One application where mechatronics will meet IoT is in the future of our manufacturing. The Industry 4.0 or Smart Industry attention is about networked modern industrial automation.

- What does it mean for the flow of goods through a manufacturing plant if knowledge of the logistics is shared, if the performance of one workstation is optimized as part of the total logistics or operation, if service and repair in a production facility is robust because workstations are flexible and can adapt?
- What does this imply for the industrial robotics and smart mechatronic production devices?
- How will this impact the design requirement of our mechatronic devices and products?

The Internet of Things will not only change the modern factory. It is estimated that in 2020, 50 billion devices will be connected to internet. This means it will be entering our households and equipment used at home, as well as our cars. When wearable electronics are pushed further, and we are surrounded by sensors, we only need the step towards actuation to be able to closed the loop and by that enter the world of mechatronics again [6]!

2.7 Towards Systems Integration

Overseeing these developments we could question what mechatronics actually is or will be. Is mechatronics being disrupted? Has it evaporated already into systems engineering, is it part of the supporting disciplines, does it enlarge to be the backbone of cyber physics? Moreover, if biological systems are also going to have technical devices implemented (Internet of Humans), what is then the role of the mechatronics discipline? How should we educate people in mechatronics thinking, how small or how broad? In Fig. 2.6 the role of systems engineering is used to enable the necessary integration of the disciplinary as well as the technological contributions.

In this book many of the mentioned developments will be addressed. We will not have definite answers for the future of mechatronics, nor for its education, but we learn also that this should be robust and adaptable because we cannot predict the future! We know for sure that the pace of technological development is accelerating, hence, so should we!

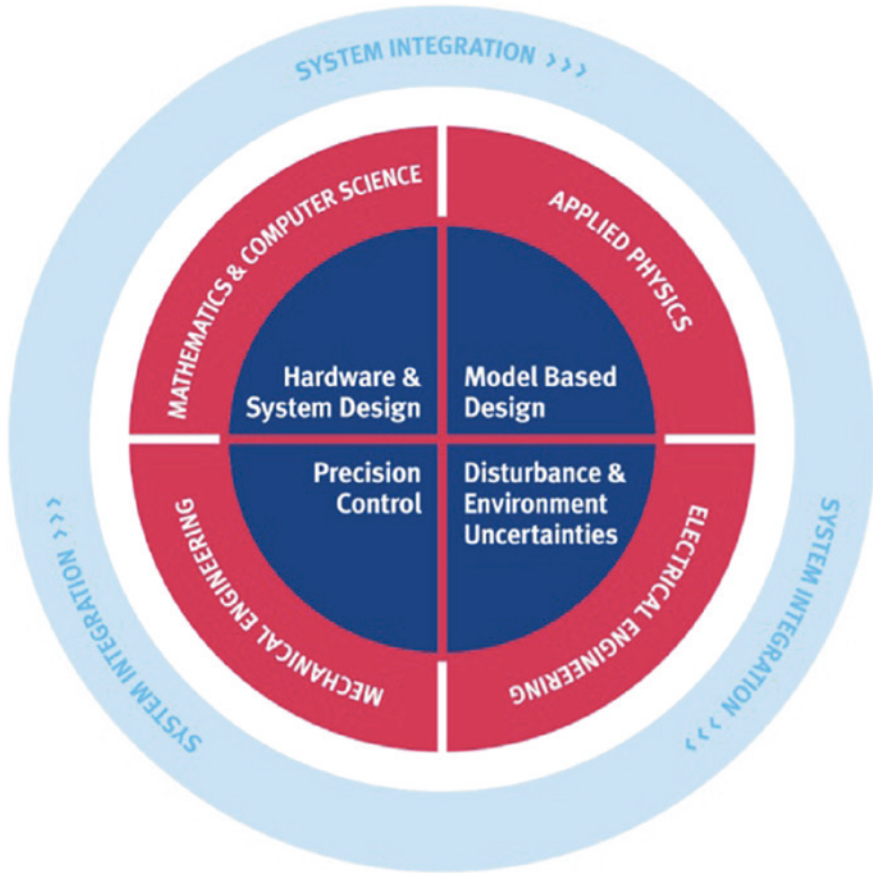


Fig. 2.6 Systems engineering integration of disciplines and technologies [4]

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Mechatronic Futures

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