MECHATRONICS IN BIOMEDICAL APPLICATIONS AND BIOMECHATRONICS

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Abstract
This paper discusses the benefits of a mechatronics design approach. Mechatronics is more than just enriching mechanical constructions with electronics. It is a systems approach, aiming at the optimal solution, by combining mechanical engineering, control engineering, electronics and computer science. The synergy obtained from such a solution leads to new designs that could not be realized in one of the disciplines alone. Parts of the functions of a mechanical system can be better implemented by means of electronics, but sometimes also the opposite is true. Control systems and appropriate sensors help to realize a predictable behavior, also in the presence of disturbances. Information technology and intelligent control algorithms make these systems more intelligent and where needed, more autonomous.

1 Introduction
At the University of Twente the mechatronics research is concentrated in the Cornelis J. Drebbel Research Institute for Systems Engineering. This institute applies results of more theoretically oriented research to the design of mechatronic systems. The institute has participants from four different faculties: Mechanical Engineering, Electrical Engineering, Applied Mathematics and Computer Science.

Mechatronics, as we see it in the Drebbel Institute, is well defined by the definition given by the *IRDAC committee of the EU* [1]:
"The term 'mechatronics' refers to a synergistic combination of precision engineering, electronic control and systems thinking in the design of products and manufacturing processes. It is an interdisciplinary subject that both draws on the constituent disciplines and includes subjects not normally associated with one of the above."

or by the *definition* given by *Buur* [2]:
"Mechatronics is a technology which combines mechanics with electronics and information technology to form both functional interaction and spatial integration in components, modules, products and systems"

A mechatronic approach has several benefits. Mechatronic systems:
- have greater flexibility
- have a better performance and higher quality
- are less expensive

Because of the systems approach, mechatronic systems also deal with:
- optimization of the whole system

Mechatronic systems have wide areas of applications. They range from consumer electronics, such as CD-players to advanced packing machines, for instance in the food industry, and modern automotive enhancements like ABS, electronic stabilization systems and active suspension systems as well as automated highways. An often cited and still powerful example of a mechatronic system is the CD-player. This was really an innovative design bringing greater *flexibility*, *better performance*, *higher quality* and a *lower price* than ever could be reached with its predecessor, the turntable for old vinyl discs.

Instead of keeping the number of revolutions of the disc constant, it aims for a constant speed of the head along the tracks of the disc. This means that the disc rotates slower when tracks with a greater diameter are read. The bits read from the CD are buffered electronically in a buffer that sends its information to the DA converters, controlled by a quartz crystal. This enables the realization of a very constant bit rate and eliminates all audible speed fluctuations. Such a performance could never be obtained from a pure mechanical device only, even if it were equipped with a good speed control system. In fact the control loop for the disc speed does not need to have very strict specifications. It should only prevent overflow or underflow of the buffer. The high accuracy is obtained in an open loop mode, steered by a quartz crystal (Figure 1).

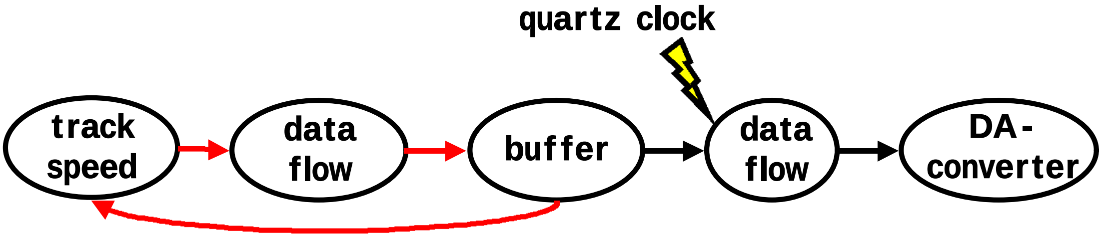

Figure 1. Combination of closed-loop and open-loop control in a CD-player

The flexibility introduced by the combination of precision mechanics and electronics has allowed the development of CD-ROM players, running at speeds more than 30 times faster than the original audio CD's.

A new way of thinking was necessary to come to such a new solution. On the other hand, the CD player is still a sophisticated piece of precision mechanics. No electronic memory device can compete yet economically with the opto-mechanical storage capabilities of the CD and its successor the DVD. But this may change rapidly. Nowadays, electronic buffers with a memory capacity of up to 10 seconds, allow the use of these devices during outdoor exercises, such as jogging. The first devices that deliver CD-quality sound and use only solid state electronics have become available already, But they still have to use audio compression techniques.

Finally, mechatronic systems design has to do with *optimization of the system* as a whole. The mechanical parts should be developed with the control system in mind. Flexibility, prize and performance play a role in this optimization process. Besides good insight in the possibilities for designing the mechanical parts, this requires knowledge of modern information technology tools, electronics and measurement and control technology. Design support for the mechatronic engineer can help to reduce the time needed to develop new products and will allow the optimization of the whole system, by changing the controller parameters and the dimensions of the mechanical system within one design tool. In the Control Laboratory research is carried out to develop such support systems, see e.g. [3], [4], [5].

Biomechatronics
Recently the BMTI of the University of Twente has started a new research program in biomechatronics. This program will get ample attention in the other presentations at this symposium. Here we will focus on the related activities in the Drebbel institute. Recently it was decided to start a program of developing mechatronic systems to support elderly and disabled persons. An example of work in this area is the development of new wheelchairs. Originally, wheelchairs were pure mechanical, human powered devices. Modern wheelchairs are not only electrically driven, but can be controlled by means of joystick. Adaptive control algorithms enable its use inside

(cautious control and low speeds) and outside (less accuracy and high speed). These algorithms are able to guarantee a stable steering performance for vehicles, that without proper control would be inherently unstable [6]. Because there are many different handicaps the flexibility that could be obtained by a mechatronic design of these wheelchairs would be of great help to adjust the wheelchair to the personal needs of the user, even if these user needs would change over time.

The aging population demands for more care for elderly people in the coming decades. If tools could be developed that enable these people to stay in their homes on their own, rather than moving to nursing homes, their quality of life can be improved and the cost of professional care reduced. It can be an area of application of home robots, as well as of robotic systems that, for instance, can give a patient a glass of water or feed someone. Such robots will have properties that completely differ from those of conventional, 'industrial' robots. The latter are heavy and will follow their path under all circumstances. Because they operate in a structured environment, in a factory, this is no problem. Home robots, on the contrary, operate in an unstructured environment, in the presence of human beings. This requires for more sensors, more intelligence and more autonomy. The robots should be human friendly, will be light and have a soft feeling, rather than being heavy and stiff. Besides a proper choice of the mechanical constructions, proper control systems will be essential for such behavior. The new program of the Drebbel Institute will concentrate on these robot-like constructions for elderly and disabled people.

Neural Networks

One of the techniques that will certainly play a role in enhancing mechatronic systems is neural network based control. In the control laboratory experience has been gathered with various applications of learning feedforward controllers. Applications include the path control of a mobile robot [7], accurate position control of an industrial linear motor system [8] and functional electrical stimulation [9], [10].

The principle of a learning feedforward mechanism can be explained with Figure 2a.

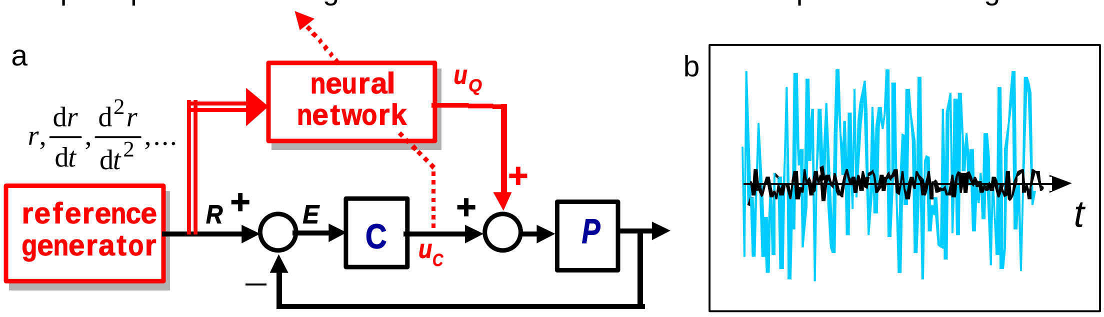

Figure 2 Learning Feedforward

The basic feedback control loop, printed in black and consisting of the controller *C* en the process to be controlled *P*, is designed for a robust behavior and does not need to have a high performance. When there are no disturbances, high performance can be obtained by means of a properly designed feedforward controller, making the feedback controller output u_C zero. However this would require perfect knowledge of the dynamics of the process. A neural network can be applied to obtain such a 'perfect' model automatically. Because in the ideal case the controller output should be zero, this signal is an indication how well the neural network performs and it can be used to train the neural network. By feeding the neural network not only with the reference signal (*r*) itself, but also with its derivatives, arbitrary trajectories can be followed. The feedback loop is maintained to deal with unmodeled disturbances and to maintain the learning capabilities in order to adapt to changes in the dynamics of the process. The learning is typically finished after a certain reference trajectory has been followed 5-10 times. Figure 2b indicates how the tracking error decreases after ten learning steps (step 1 gray curve, step 10 black curve). Theoretical research has given stability properties and design rules to properly select the dimensions of the network [11]. If the network is too small, the desired trajectory will not be accurately followed. If the network is too big, stability problems may occur because the network will learn stochastic variations, rather than the inherent properties of the process.

Conclusions

In this paper it has been discussed how a mechatronic design philosophy can enhance the flexibility and performance of biomedical systems, as it has already done in several other applications. Examples of projects in the Drebbel Institute, such as an advanced wheelchair and robots for handicapped and elderly people have been given. The application of neural networks to learning feedforward controllers has been discussed a little bit into more detail.

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