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40 YEARS IN A PLAYGROUND

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Valedictory address

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BY

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The figures 1 (left), 5, 6, 11, 15, 20, 27, 37 are from the www (in some cases edited). All other figures are from my private collection.

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INTRODUCTION

In the 45 minutes I have available to look back at over 40 years of work as an engineer, researcher and teacher, I would like to take you through some of the activities I have undertaken during this period and try to find a line in them. On a recent visit to our daughter Renée in the US, one of her colleagues at Stanford University asked "What is it like, being a professor?" This question seemed like a good starting point for this valedictory address, in which I want to look back on a period of 40 years of being active as a control engineer in teaching and research. My answer was that it is indeed a very nice job - and sometimes not so nice - but that you should also and above all enjoy the opportunities you have as a young researcher, who is not yet bothered by financial problems and can just be busy. I had plenty of opportunities to do so, not only in the beginning, but also at the end, when I was able to devote myself to setting up and helping to realise the challenging new study ’Creative Technology’. I look back on the past few years with pleasure. It is as if I have been working in a playground for 40 years. The message that you can have a lot of fun in engineering in general and control engineering in particular cannot be preached often enough to students who want to choose a challenging and fun study and later an exciting profession. Hence the title of this story. According to the review committee, we should also, above all, tell potential students how useful electrical engineering is. So I will certainly do that under the motto ’Great that fun can also be useful’. Let me first take you through the different phases of my career and then go into a few topics in more detail.

The engineering study: 1965–1971

Let me start at the beginning. Having become enthusiastic about studying electrical engineering at grammar school, partly through the lessons of maths and physics teacher and electrical engineer Van de Putte, I decided to study electrical engineering in Delft. In the period from 1965-1971, I was treasurer of the study association *ETV* for one year, student assistant at the Laboratory of Control Engineering for two years, and got my engineering degree.

During what would now be called an undergraduate assignment, I worked on simulating the automatic control of an infusion, first in hardware and later on the computer. My thesis work was on the optimal production of electrical energy. The problem was to minimise production costs over a 24-hour period, based on some predictable pattern of electricity demand during that period. The result was an optimal choice of production units to be used and the optimal distribution of power across those units. In parallel, from my student assistant job, I worked on modelling the dynamic behaviour of a number of generation units at the *Hemweg power plant* in Amsterdam. *Modelling*,*Control* and *Optimisation* were the keywords of this work and have remained so for the next forty years. To these I would add the keyword *Systems Approach*.

Military service: 1971–1973

After graduation, I had to go into military service. That meant going to Prof Van Nauta Lemke, who had good contacts with the navy and helped all his graduates get suitable positions. The best positions were the two places for naval officers to do research on adaptive autopilots for ships at the Control Engineering Laboratory. I managed to secure one of these places and so I entered the world of ship control. The aim of the adaptive autopilots project was to design an autopilot that, without setting buttons, would also be usable for naval vessels. This was preceded by a nine-week naval officer training course, during which I learnt useful stuff, such as saluting with the sabre. During my military service, my contacts with the *Royal Netherlands Navy* were largely limited to spending a night at the barracks in The Hague once a month, when I had to play officer of the watch there.

Scientific Staff member THD – PhD: 1973–1982

When military service was over, nothing really changed. I remained in the same chair behind the same desk. Only my salary now came from the THD. And instead of being busy as a naval officer myself, I now always had two serving officers under my care, who, like me, worked on adaptive autopilot during their service at the Control Engineering Laboratory. This period concluded with my indexPhD in 1982 on the subject of, how could it be otherwise, Adaptive Steering of Ships' [8] Incidentally, during all these years, I was also still involved in projects on *Modelling*, *Control* and *Optimisation* of ewlectricity generation[9]. For both projects, measurements were done regularly, both on board various naval vessels and in electrical power plants.

Scientific Staff Member THD/TUD: 1982–1987

After my PhD, I thought it would be good to do something completely different. That didn't quite work out, as a new project presented itself in the form of a request from the navy and Van Rietschoten and Houwens. The aim of this project was to develop an autopilot that, apart from being able to make a ship go straight or make a turn, uses the rudder to counteract roll motions, so-called *Rudder Roll Stabilisation*, or RRS for short. In my thesis, I had shown that optimal steering means moving the rudder as little as possible. RRS required constant violent rudder movements. Reason enough to see in this a new scientific challenge [5].
Even though I was always engaged in *control*, I had always managed to avoid *administrative* positions such as member of the faculty council, partly with the excuse that my dissertation had to be finished first. Now that that no longer applied, I became a candidate for and then a member of the faculty council. When a member of the faculty board was sought a little later, it was an opportunity to be more directive instead of controlling, and I became "Portfolio Holder Research". My first task was to introduce a so-called model-based allocation of funding and later the distribution of UHD places among the departments. During this period, I saw that *Modelling*, *Control* and *Optimisation* also play an important roll in managing an organisation.

Professor in Control Engineering UT: 1987–2011

In 1986, there were several vacancies for professors of Control Engineering within the Netherlands. And because I got the idea during my time on the faculty board that I was up for that, I wrote a couple of letters of application for the first time in my life, one of which went to the UT. At the moment suprême, I could choose between two offers. I never regretted that I chose Twente –if only because I traded the daily 30-90 minute drive in Randstad traffic, for the 6 minute bike ride in the beautiful Twente countryside.

With my departure for UT, I left the autopilots in Delft behind and henceforth Mechatronics was the keyword, containing perhaps even more than before the elements *modelling*, *control*, *optimisation* and *Systems Approach*. Mechatronics is a systems approach at the interface of mechanical, electrical and computer engineering. I will come back to this in detail later. In 1989, the (MRCT) was founded, a collaboration between groups from the faculties of electrical

FIGURE 1 60 minutes of traffic jams exchanged for 6 minutes of fine cycling

engineering, mechanical engineering, mathematics and computer science. In doing so, we were global pioneers in this field, which has only become more important since then, [30], [38], [40]. I became chairman of the MRCT.
In Delft, I had had plenty of time for research myself, along with graduate and doctoral students [44], [45], [19]. At the UT, my work became more co-ordinating and guiding. The emphasis shifted more towards teaching. Among other things, I taught the basic course in Control Engineering for all those years, and I was involved in supervising some 400-500 graduating students. Another important teaching activity during that period was chairing the CO-CUREL, which met every Friday afternoon from four to sometimes seven o'clock for over two years. This was not, as the name and time suggests, a cooking club, but the COmmittee CUrriculum revision ELectrical Engineering. During that period, the curriculum of the then four-year study was completely revised and redesigned from scratch –nowadays called a 'green field approach'. Apart from modified content, all kinds of new teaching methods were introduced. All teachers were involved in this and during the regular 'hearings' things got heated at times. The result, in any case, was that study yields already went up during this process and continued to rise thereafter. The designed curriculum proved to be very robust, adapting without much change to the extension of the study from four to five years and to the bachelor-master structure. Since then, the Electrical Engineering programme has consistently scored as number one in Elsevier's annual ranking.

During the period when we had a 4-year study programme, the idea was that a substantial proportion of students would go on to a second phase, either as PhD students or as participants in a designer course. From the UT, we then set up the course Mechatronic Designer, in which TUE later joined. We trained quite a number of designers during that period who later got very good and relevant jobs in industry. When the study went back to five years, the enthusiasm for this programme waned. In itself, that 4+2 or 4+4 structure was a good idea. Too bad that by the time such a structure takes shape and becomes successful, everything changes again.

Dean EE: 1994–1998

In 1994, I was called upon to become the dean of the Faculty of Electrical Engineering. I enjoyed doing that for several years. As an important result of that period, I see that there has been an extremely pleasant atmosphere of cooperation among colleagues ever since. The relationship with the then Faculty Council also changed during that time from ‘a fight with the opposition’ to ‘making something good out of it together and standing up for it’. The new Higher Education Act (the MUB) led to all kinds of new structures, in which everyone had to ‘find their position again’. That made the last year of this period the most difficult. Gerda and I thoroughly enjoyed the subsequent six-month sabbatical at the University of Newcastle in Australia.

Scientific director Drebbel Institute: 1999-2004

After my sabbatical, university politics made it necessary to transform the well-functioning informal collaboration in the MRCT into a more formal research institute. This led to the creation of the Drebbel Institute for Mechatronics. Due to all sorts of political wrangling and change of personalities, this never became as successful as the MRCT. This is one of the few things I look back on with less pleasure.

Chairman Department of Electrical Engineering: 2005–2011

Meanwhile, in the process of clustering faculties and a limited number of research institutes for the entire UT, the faculty of EEMCS (Electrical Engineering, Mathematics and Computer Science) had emerged. In 2005, when the position of departmental chairman became vacant, I said yes again anyway. I held that position from 2005 to August 2011.

Creative Technology: 2008–2011

To halt the declining number of students opting for engineering, EEMCS decided several years ago to start a whole new degree programme ‘Creative Technology’ or ‘CreaTe’ for short. This course combines elements of electrical engineering, computer science and ‘art’. Graduates of this programme should be able to create products that make life more pleasant or easier, ranging from innovative aids for the elderly to computer games, serious or otherwise. In short, a course that deals with all kinds of things I like. So I did not have to think long when the dean, Ton Mouthaan, asked me to help set up this study programme two days a week. The consequence was that the group needed a successor.
Of course, there was already one in the person of Stefano Stramigioli. When, counting my student assistant time, on 1 September 2009, I celebrated 40 years in government, I handed over the gavel of the group to Stefano. And from then on, I could devote myself in a rooftop structure to also implementing the CreaTe teaching. It was extremely pleasant to be able to fully commit myself to this new challenge in this way, unencumbered by departmental management tasks.
Education has played an important role all these years anyway. The Control Engineering group was always one of the most popular groups among Electrical Engineering and Mechatronics students to graduate. I estimate that we have delivered between 400 and 500 engineers over the past 24 years. Since 2000, all students who come along to do an undergraduate or graduate assignment are photographed, initially via webcam and since 2002 via digital camera (see photos on the following pages). Unfortunately, such photos are missing from the 13 years before 2000.

Playground

This list of all my activities does not yet directly explain the title of this speech ‘40 years in a playground’. Therefore, I will now discuss a few examples from all these periods that make it clear why I experienced this as being usefully busy in a high-tech playground. Especially in the beginning, I was intensively involved in the research myself. But I will also give a few examples that mainly illustrate what this field is all about.

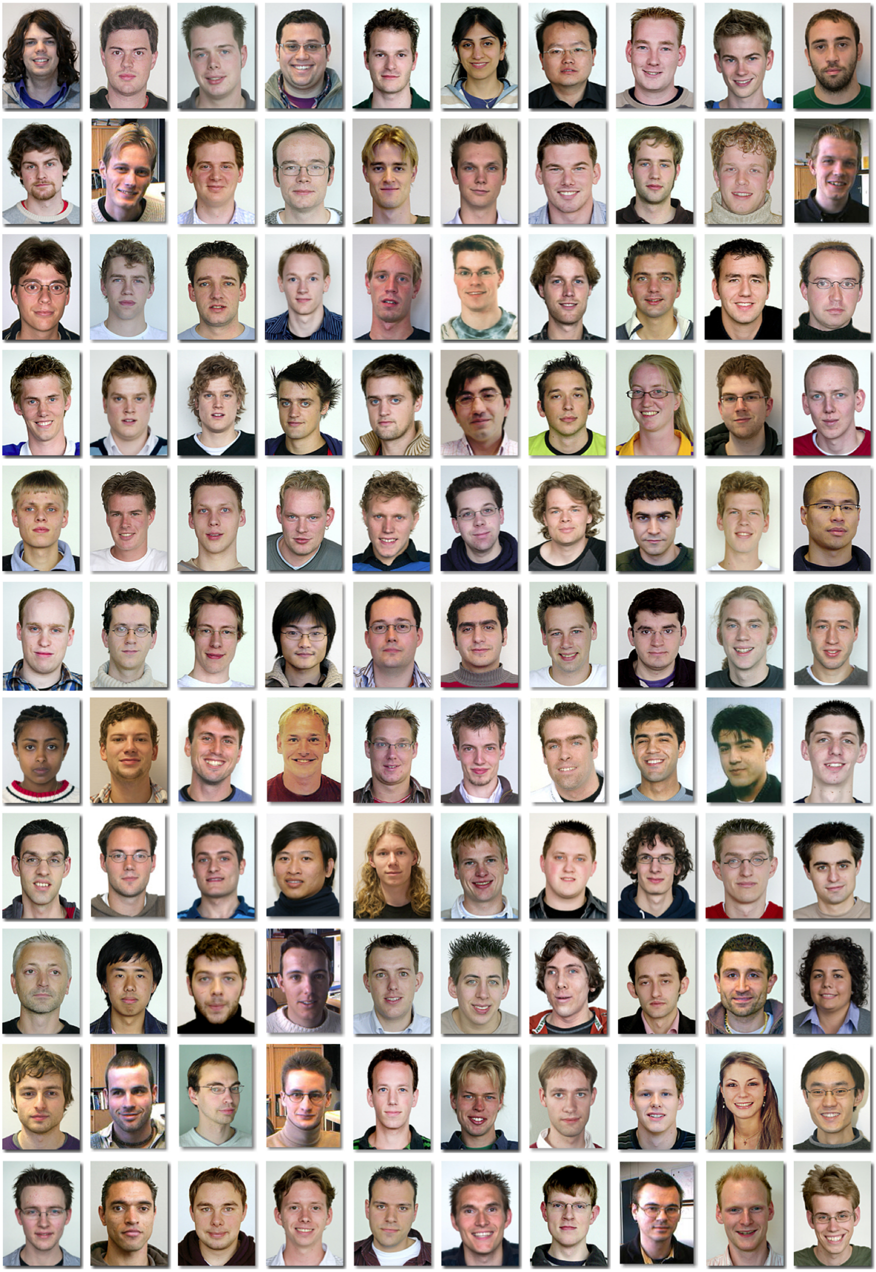


FIGURE 2 Students 2000-2011 (a)

FIGURE 3 Students 2000-2011 (b)

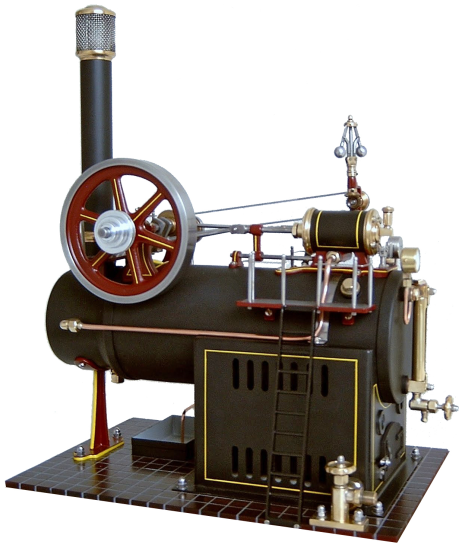
FIGURE 4 Students 2000-2011

Years in Delft

Steam Machinery

My thesis work was on the 'optimum production of electrical energy'. This must take into account the expected demand for electrical energy and the fact that turning such a large unit on and off also takes time to heat up, and thus money. Moreover, the production costs of the units are not all equal and depend on the power they produce. So when solving such a problem, you have to take into account what has happened in the past –is a unit used recently– and what will happen in the future –is the unit I would like to turn off now, needed again soon. We call this taking into account the dynamics of the system.
Directly related to this is the so-called 'Power Frequency Control' which aims to ensure that all interconnected power plants in Europe, together realise a mains frequency of exactly 50 Hz. That means that the generating units in all those power plants have to run at exactly the same speed. We were regularly approached by power producers in my early years as a scientist who had problems with that regulation. That usually meant that we would first take measurements with a graduate student to see exactly where the problem was. Then, using a model, we arrived at a solution. Then, and that was the most fun, we would test whether that solution also worked on the real unit, often of a few hundreds of MWs.
Figure 5 shows a model of a 'steam engine'. The pressure of the steam causes the wheel to turn. If this wheel is connected to a generator—say a large dynamo—then we can use it to generate electrical energy. To make sure the machine turns at the right speed, there is a regulator on the top right of the machine, also known as the 'Balls of Watt' or Watt regulator [82].
If the machine speeds up, the balls swing further out, squeezing the steam supply. If the rpm is too low, the balls drop back down and the steam supply is increased. I have come across quite a few more of these regulators. Nowadays, of course, such regulators are electronic or software-based. Playing with such a steam engine is fun, but doing tests with a unit of a few hundred MW is even more fun (figure 6) and exciting. If there is an amplifier too much or too little in the controller under test, the steam turbine will oscillate. In our case, that meant power variations between about 25 and 200 MW, resulting in the whole building shaking. While that was very exciting, it was not the intention, of course. During that period, measurements were made at power plants in, among other places, Borssele, Lelystad [4] [14], a water plant in Terneuzen and

FIGURE 5
Model steam engine [77]



at the total-energy plant at Zwembad Kerkpolder in Delft.

Steering of Ships

Thanks to the military service, my next area of research was ship steering. The Royal Netherlands Navy was interested in an autopilot that adjusted itself to changing conditions, such as changing speeds. Merchant navy autopilots at the time were mainly developed to keep a ship on course in barely varying conditions. During my military service, regular measurements were taken aboard the pilot boat Capella. The purpose of the tests was initially modelling steering behaviour and later testing a first version of the adaptive autopilot. A modelling package was developed on the PDP-9 that allowed a mathematical model to be created based on the measurement results. During my military service, a first version of the 'Adaptieve Stuur Automaat' (ASA) was tested as well [1, 2] (figure 7).

Even before my military service, it had been decided that I would stay on as a scientific staff member in the Control Engineering group. When my military service was over, it was alomost obvious that I would continue researching autopilots for ships, supported by naval officers (like a was before). The collaboration

FIGURE 6 Electrical power plant

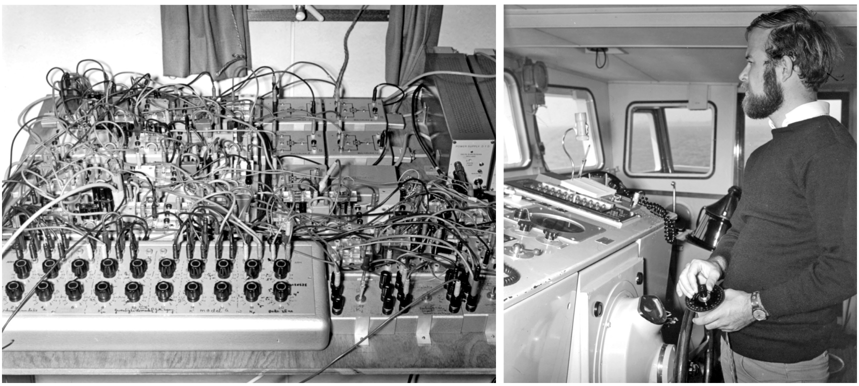


FIGURE 7 left: Autopilot, build with op-amp modules
right: Adjusting the desired heading with a potentiometer

with the navy became more intense than it had ever been. Every year I was at least twice for a week or two aboard a navy ship for measurements. As with any control engineering problem, research began with modelling, to understand the behaviour and see how you could influence it. The modelling tests always had to be done in nice weather, so that was pleasant. Unique were the good contacts with the KM through the committee that supervised the work of naval conscripts and with the supervisors of graduating students from KIM. A phone call was enough to spend another couple of weeks with the KIM's training ship, the Zeefakkel (figure 8) or get a frigate as a test object for a fortnight.

FIGURE 8 Turning circle and zig-zag trials with the 'Zeefakkel'

With the KIM's training ship, the Zeefakkel, we spent many weeks on the IJsselmeer and once in a Norwegian fjord. The time Gerda was allowed to come along from Enkhuizen back to Den Helder, we were even allowed to spend the night in the captain's double bed. With several other navy ships, there were trips to Norway, Scotland and Portugal. Enjoying rice table on deck off the coast of Morocco gave the feeling of being on the road with Hr.Ms. Cruise Enterprise.

The first experiments with an adaptive autopilot took place during my service, in 1972, aboard the pilot boat Capella. Digital computers were not then an issue for this kind of experimentation. The autopilot was built with analogue 'operational amplifiers' that we had screwed seaworthily to a board (figure 7). It was a primitive setup, but we could demonstrate that the basic principles worked.

The last trials of the Adaptive Steering Autopilot (ASA) in 1979, thanks to advancing technology, we were able to carry out with a 'small' computer system: the LSI-11 DECLAB system (figure 9). This was successfully used during trials aboard the oceanographic survey vessel Hr.Ms. Tydeman and the supply ship

FIGURE 9 DEC LSI-11 computer with the user interface

Hr.Ms. Poolster. In addition to all the desirable features of the adaptive autopilot, such as its ability to self-adjust, we were also able to demonstrate fuel savings of a couple of per cent ([6, 11, 12, 16, 22, 37]).
To gain further insight into the potential for fuel savings, we found the MARIN in Wageningen willing to provide us with a towing tank containing an expensive 'toy boat' (figure 10) for two weeks. During these trials, savings of up to 5% were indeed demonstrated [7].
During the trial set-up, a lot of attention had been paid, via a thesis project, to ensuring that the control panel on the bridge was reliable and, above all, looked reliable (figure 9). This proved very important to enable the crew to use the set-up even when we were away for a while. Still, the commander of Hr.Ms. Poolster told us that he would never do a 'replenishment at sea' operation (figure 11) on autopilot. After we had done it a few times anyway with our adaptive autopilot and had already established the settings for the autopilot, it became standard to do it on autopilot. You come across that more often, fear of the autopilot, but after getting used to it for a while you do realise that such an autopilot can often do it better and safer than humans.

FIGURE 10 Trials at MARIN: 5% fuel savings demonstrated

FIGURE 11 Replenishment at Sea (RAS) operation

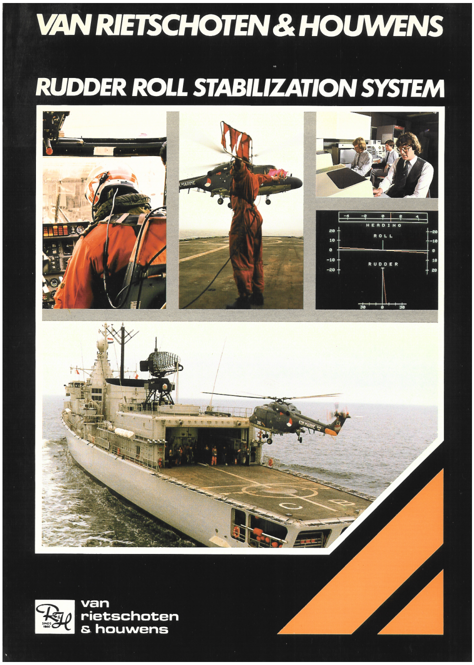
To carry out the final tests, it was necessary to purchase a 'mobile' computer system. This easily meant a total investment of € 50 000 in the late 1970s. For that, we entered into a third-party money-making contract with ', a company that wanted to build the autopilot and later worked with us to create a beautiful design for it (figure 12). Curiously, this met with resistance from some colleagues at the time. The fact that the TUD lawyer had to get involved shows that such contracts were far from standard back then.

FIGURE 12
Brochure ASA (Observator)

Rudder Roll Stabilisation (RRS)

As mentioned earlier, after the completion of the Adaptive Autopilot project, the request came from the Royal Neterlands Navy (RNN) and Van Rietschoten and Houwens to research the possibilities of rudder roll stabilisation. It was the beginning of many years of collaboration with Van Rietschoten and Houwens and, in particular, Dick Beekman. Van Rietschoten and Houwens paid an employee for four years for this research. After four years, it had been shown that the system, based partly on the algorithms of the adaptive autopilot, could achieve the desired roll damping. The RNN made the necessary modifications to the ship's design (in particular, a much faster steering gear) and implemented this system on the M frigates. Van Rietschoten and Houwens then supplied the system, among others, for fast container ships (figure 13). During the research, it turned out that there were quite a few fundamental problems to be solved [15], [20], [21], [23]. The result was that the staff member concerned was promoted on it. As this PhD took place just after my appointment as a professor at UT, Peter van der Klugt was not only the first PhD student that I supervised, but this was also my first appearance as a PhD supervisor [44].

FIGURE 13
Brochure Rudder Roll Stabilisation (Van Rietschoten en Houwens)



TWENTE: MECHATRONICS

Mechatronics is a systems approach that, through an optimal combination of mechanical and electronic components and a control system, usually realised in embedded software, leads to superior products with properties that would not be possible without this synergistic combination.

This may sound like abracadabra. Therefore, I will try to make this clear with a few general examples.
Figure 14 shows the development from the 16-kilogram purely mechanical

FIGURE 14 From typewriter to virtual keyboard:
Top left: typewriter, top right: ‘Teletype’
centre left: IBM Selectric ball, centre right: PC keyboard
bottom left: Apple keyboard, bottom right: virtual keyboard iPad

typewriter on which I typed my graduation report (top left), through the teletype, a mechanical device with some electronics that allowed me to programme the PDP-9 at graduation (top right), to the virtual keyboard on the screen of the iPad (bottom right). Adding electronics allowed IBM to create the typewriter with the interchangeable ball. The advantage of this was that you could type other fonts very easily. At the time, the formulas in my thesis were produced by the secretary using an IBM typewriter with spheres. Of course, printing via a matrix printer, laser printer and inkjet printer became increasingly flexible. A modern inkjet printer, which can print not only all kinds of fonts but also photos, is a true mechatronic device. Until recently, keyboards still looked very much like teletype keys, like the 'modern' PC keyboard in the middle right. Apple, at the bottom left went a step further, with a minimalist keyboard. Finally, at the bottom right is the iPad's (virtual) keyboard, which exists only on the screen as an image and can therefore change very easily, depending on the activity. The keys are different when creating an e-mail than when typing a piece of text. Incidentally, in many cases, such an iPad also makes printing unnecessary and is really just the beginning of a paperless office. So by adding electronics and software, we can make systems increasingly flexible and also cheaper.

Mechatronic view on the world

A characteristic of mechatronics is that you look for solutions across domain boundaries. Sometimes something can be solved better mechanically, sometimes better in electronics or software. This requires that designers of mechatronic systems can think multidisciplinary and know what is possible with mechanical, electronic and software parts of a system. In classical control engineering, we always assumed a process to be present that we wanted to 'control', by adding a controller to it. Examples include a thermostat that keeps the temperature in a room constant. Another example is the aforementioned autopilot that can keep a ship on course or change course in a predictable way. I would not yet call this mechatronics. A true mechatronic design starts with modelling, creating an abstract, domain-independent description that allows us to look for solutions across domain boundaries. In the Control Engineering group, a method was developed for this, port-based modelling' that makes this easy to do. The result of a number of PhD projects [48, 55, 56] has led to the software package 20-sim and a spin-off company, Controllab Products, which markets 20-sim and also carries out all kinds of consultancy projects with it. Controllab Products currently employs seven people.

Cars

Mercedes launched a new car several years ago, the A-Class. In the so-called elk test, in which the car has to zigzag quickly around a number of obstacles, the car turned out to tip over because with its relatively high body, the centrifugal forces became too great. So then you have to come up with something that generates a counteracting force that prevents the overturning. The solution, as shown in figure 15 is not really realisable in this respect.

FIGURE 15 Mechanical solution for a failing elk test

We could then, of course, try to design a completely different car. Another possibility is to look for a solution in a domain other than the mechanical one. With a *sensor*, we can measure the forces on the car. With this *information*, we can calculate the counteracting force needed to compensate for the centrifugal force. If we can then apply this force to the car with an *actuator*, we can prevent the car from overturning. The design problem is then choosing the right sensors and actuators and finding the right algorithms, say formulas, to achieve the same as would be possible with support wheels. This is the thinking behind systems such as ESP (Electronic Stability Programme), which are now standard in all more expensive cars.

Going one step further is the Segway (figure 16), a scooter that, with no additional aids, if you stand on it, immediately falls over. You can, of course, add a third or fourth wheel, but a mechatronic solution is much more elegant.

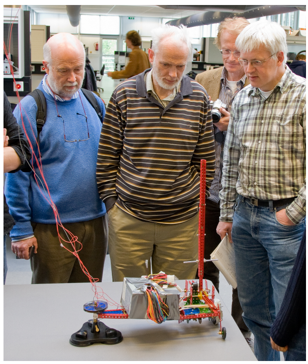
FIGURE 16
Segway: only stable because of Mechatronics.

The electronics in the Segway measure the angle that the steering rod makes with respect to a desired vertical position, the dual computers determine what forces are needed to correct a deviation, the two motors that directly drive the wheels then ensure that the Segway maintains the correct vertical position. Because of this *system approach*, realisation is not hindered by mechanical constraints. The overall system, construction and steering are designed as a whole. The otherwise necessary 'third wheel' is here virtually realised in software.

You could think of the Segway as a commercial product, born out of a classic control engineering practical experiment: the balancing stick. By itself, this seems like a useless, playful experiment, but it is a model for, say, the Segway (figure 17).

FIGURE 17
Balancing stick

Result of the mechatronics project for second-year Electrical Engineering students. This project integrates theoretical knowledge from the subjects Measurement Engineering, Mechanics and Transduction Engineering, Dynamical Systems and Control Engineering. In a fortnight, students create a design, simulate it on the computer and, if it seems feasible, it is realised with building materials and components already present (or purchased for up to € 50).



Electrical engineering suffers from an Image problem. If you see a car driving with ‘Electrotechnology’ on it, it usually belongs to an Electrical Installation firm. More an association with pulling wires than high tech. That’s why we call the programme ‘Electrical Engineering’ these days. But that does not change the fact that much of that electrical engineering is hidden, or embedded. To show that electrical engineering is there even when you don’t see it, a couple of years ago, the Electrical Engineering professors all went out in there gowns on a Segway to the opening of the academic year [83] (Figure 18). This attracted a lot of media attention and the following year we had twice as many freshmen. I cannot prove that this was because of this stunt, but we did not see such a jump in intake after that. Time for another stunt?

FIGURE 18 EE professors in training for the opening of the academic year: that’s another playground

Incidentally, the inventor of the Segway Dean Kamen was also impressed by this experiment (figure 19). He too was concerned about the lack of interest among young people in technical education. To this end, he founded the FIRST® organisation ‘to inspire young people’s interest and participation in science and technology’ back in 1989 [78]. Winners of competitions organised by FIRST® were hosted by President Obama at the White House!

FIGURE 19
Dean Kamen (right), the inventor of the Segway, looks at photos from the opening of the academic year

Trains

If you are travelling from Enschede to the west on the train, coupling is always required in Deventer. If it is freezing a few degrees or it has been snowing, this regularly causes difficulties and delays. Some time ago, we looked for alternatives in a number of projects with students in a model railway. For example, as shown in figure 20, you could equip the trains with a large spring so that coupling is no longer necessary and the rear train can just push the front one forward. Complicated mechanical coupling mechanisms are then no longer needed. The NS, rightly, will not appreciate such a solution.

FIGURE 20 Alternative coupling mechanism: virtual spring

But we can also tackle this mechatronically. With a *sensor*, we can measure the distance between the two trains. Using the motors (*actuators*) of the second train, we can control its speed so that the distance between the two trains remains constant. In doing so, we have created a *virtual*, *mechatronic spring*, so to speak. It works exactly like a real spring, only you don't see it. For pairing,

this might not be such a practical solution. But we can think of a variant. If we equipped all trains with a slightly longer (virtual) spring, we could avoid collisions with it. Probably the NS does not see that either, but that has more to do with conservatism.
After all, is this a plaything or the future? Not at all. More and more cars today have Cruise control. Cruise control is able to maintain a constant speed without the driver having to accelerate. The more modern version of this, often called *Adaptive Cruise Control*' (ACC), is none other than the virtual spring just discussed. As soon as a car with ACC approaches a slower moving car in front, the ACC brakes until its speed equals that of the car in front and there is a safe distance between the two cars. The ACC also intervenes if another car suddenly shoots between them. ACC is one of the safety features present in slightly more expensive cars these days. Already, more than half of the price of such cars is determined by mechatronics in the form of electronics and software: ABS, ESP, ACC, Parking Assist, airbags. These features are already contributing in a major way to the fact that there are fewer accidents with fatalities or serious injuries in recent years. Recently, we owned a Toyota Prius, which is packed with these mechatronic achievements. I must say that I am particularly impressed with the adaptive cruise control. This is an example of how a few simple experiments with a toy train can be the basis for important innovations, even though we were not directly involved in this particular development.

FIGURE 21 Adaptive Cruise Control: virtual spring

This is just a beginning of what is possible. I am convinced that a solution to the traffic jam problem, without more asphalt, is a mechatronic one. In a few years, we will no longer have to do anything on the motorway other than read the newspaper on the iPad-32. In addition to adaptive cruise control, automatic 'lane-keeping' and 'car-to-car communication' will ensure that the (then undoubtedly electric) cars will move at 100 km per hour on a virtual track like spring-coupled train carriages at a distance of a few metres from each other (figure 21). This can dramatically increase the capacity of a road. And speaking of cars: with the replacement of the petrol engine by an electric motor, another piece of pure mechanics disappears.

Mechatronics Research at the UT

The moment I started at UT as a professor, in 1987, coincided with the beginning of mechatronics. As mentioned, explicit mechatronic design implies that by looking for a solution in the most appropriate domain, you can arrive at an optimal design. UT and a number of industries in the Netherlands were true mechatronics pioneers.
Upon my inauguration, I submitted a grant application of fl. 2.75 million to the Ministry of Education under the 'vernieuwingsgelden' with the aim of developing Mechatronics as a focus at UT. Its allocation led to the establishment of the Mechatronics Research Centre Twente (MRCT). To learn the trade and promote cooperation, we, together with colleagues Kees Heuvelman, Albert Schoute and Arun Bagchi, took study trips to Japan and the US. We noticed that mechatronics was already a hot topic in Japan, while in the US we had to keep explaining what we actually meant. The grant made it possible to start a large joint project. Together with Rien Koster, who opted for the mechatronics approach at UT from Eindhoven, it was decided to build a mobile robot that could independently navigate through a factory collecting parts along the way and using them to assemble a product (figure 22).

FIGURE 22
Mobiele Autonome Robot Twente, shortly MART [81]

This project led to several patents and eventually to an impressive, working robot, the Mobile Autonomous Robot Twente, or MART for short. Things like fully automatic driving and adaptive cruise control had already been realised in this robot. One of the innovations was an intelligent control system that used deviations from the desired trajectory to *learn* the appropriate corrections, increasing the trajectory tracking accuracy by a factor of 10. Dennis Schipper, the project leader of the MART [34], later co-founded the spin-off company Demcon with Peter Rutgers, one of the first graduates of the Mechatronic Designer course.

Mechatronics and the associated systems approach have been at the heart of research and teaching all these years. Modelling using bondgraphs is an essential part of this. This makes it possible to model physical systems that extend across different domains. The basis for this is the gate concept: components of the model are linked to each other via power gates. If two submodels have the same gate properties, they can be linked together without knowing exactly what the submodel looks like internally. This is a very pleasant feature when designing a mechatronic system. During the initial design phase, very simple submodels can be used. Later, these submodels can be replaced by more complex versions, without changing the structure (the interconnections of the submodels).

FIGURE 23
20-sim:
pronounced in English: Twente-sim

Even before my arrival, UT was gaining world fame with the programme TUTSIM. This was one of the first simulation programmes available on various platforms, including PCs. To support port-based learning and simulation with bondgraphs, the 20-sim programme was developed under the direction of Peter Breedveld, which involved several PhD students [48, 55, 56, 60, 66, 74]. The completion of the PC version, in a project together with the Ou, made the programme accessible to many users. 20-sim has evolved into a powerful mechatronic design programme (figure 23 [35, 36]. It will be marketed by our spin-off company (Controllab Products, of which the group still holds 50% of the shares. Results of the lab's research are still finding their way into new versions of 20-sim [70, 72].
With a good model, a good control system can be made. However, if the model is less well known, or the process properties vary during operation, then Adaptive [10, 19, 24, 49, 26, 53, 54] and Learning Control Systems [3, 28, 29, 31, 39, 52, 62, 67, 68, 75] can ensure that behaviour remains optimal. Particularly good results have been achieved with learning feed-forward schemes under the leadership of Theo de Vries. PhD projects have investigated whether the port-based approach can also be used in designing control systems. This has led to 'agent-based controllers' [64, 76].

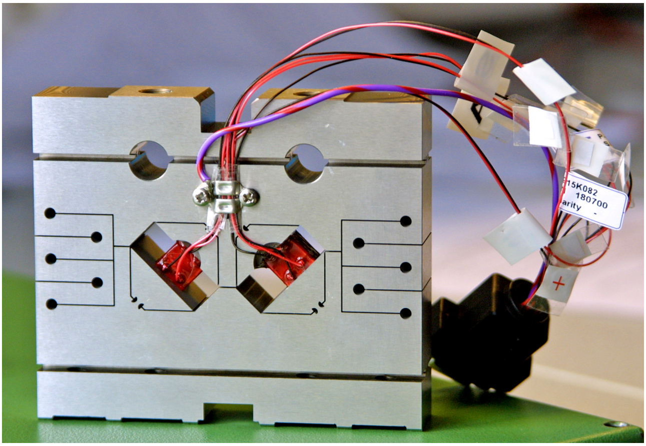


FIGURE 24
Smart Disc

Mechatronic applications were mainly in projects with companies, for example with Van Rietschoten and Houwens, Unilever and Philips. Furthermore, in STW, IOP and EU projects. Several projects were related to vibration damping [28, 32, 33, 46, 59, 61, 32], e.g. in ASML's Wafer Steppers [65]. The result of the IOP Smart Disc project is an example of this (figure 24).

Education

Education has always been important for the Control Engineering group. The group was popular with students, who often found jobs directly linked to their studies after graduation. With 400+ engineering graduates and 33 PhDs, this made an important contribution to the Dutch economy, especially the mechatronics industry. I have been 'in' for experiments in education all these years. I was involved in a trio of courses at the Open University, including the very first course completed in 1984: *Systems and their controls*' [7]. Later, this was followed by the courses *Control Engineering* [20] and, together with Peter Breedveld, 'Dynamical Systems'. [27] (figure 25). The latter two have since been used in teaching at UT and various other educational institutions. All lectures of the basic course in Control Engineering are on the Internet, so that students who missed a lecture can still listen to and watch the lecture [80].

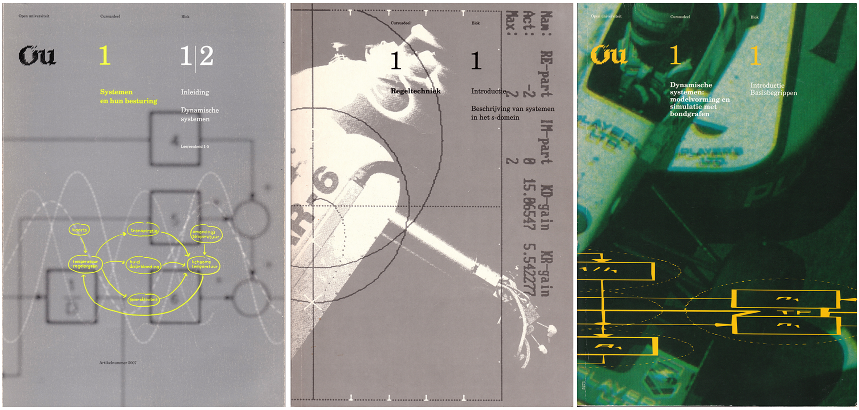


FIGURE 25 Courses in cooperation with the Open University:
Systems and their Control, Control Engineering and Dynamical Systems

FIGURE 26 33 Theses supervised as (co)promotor [44]-[76]

Contributions to Society

In addition to supervisor of 400–500 engineers, I was also supervisor or co-supervisor of 33 PhD students (figuur 26) [44]–[76]. The PhD projects covered a wide range of topics, ranging from adaptive control and Delft-era ship control to a variety of mechatronics-related topics (modelling, intelligent control, mechatronic design, real-time computer control).
Of most of these PhDs, I was able to find what they are currently doing. What is striking is that almost all of them have stayed very close to the group's research with their work: ranging from precision mechatronics, automotive, ship and offshore automation, surgical robots, to various software functions:

- Sr. Director Systems Engineering at Medtronic CRDM, Greater Minneapolis-St. Paul Area, USA
- Manager Software Development at Assembleon, Eindhoven
- Associate Professor of Embedded Control Systems at University of Twente
- Fellow at ASML, Veldhoven
- Technical Leader - Active Safety - Volvo Cars, Zweden / Adjunct Professor Mechatronics at Chalmers University of Technology
- Director and Owner, imotec b.v., Hengelo
- Manager Product Development at MPS Red Meat Slaughtering B.V.
- Project manager at TNO
- Systems Analyst at Intuitive Surgical, Sunnyvale (CA), USA
- Project Manager Platform Integration at SKF, Nieuwegein
- Advanced process control consultant at Shell Global Solutions
- Technical Consultant at Imtech ICT TS
- Hoofd Informatisering & Automatisering at Raad van State
- Senior requirements engineer at MeteoVista
- Software Architect at Esprit ICT Group
- Product Marketing Manager at ASML
- Senior Consultant Knowledgement Management & Innovation at Imtech Marine & Offshore
- Director at ASML
- System Engineering Manager at Thales
- VP Technology (Principal Architect) at Acision

Three spin-off companies have emerged from the work of the past 24 years:

- Demcon, High-tech mechatronic engineering
- Controllab Products, developer and vendor of 20-sim and mechatronic consultancy
- imotec, High-tech mechatronic engineering

Creative Technology

A few years ago, when the dean asked me to help set up the new English-language course in Creative Technology, in short, CreaTe I said yes without hesitation. In fact, everything I like happens there: new technical things that also look nice, from web design and fun gadgets to useful designs for the 'aging society', which I am now heading towards myself. The basic idea is that a lot of technology can simply be bought. You just need to get the right idea to creatively combine these components into fun, beautiful and useful systems. Knowledge of dynamic systems, as my subject is called in the curriculum, is important for this, but the field is much broader and it has been a challenge and a lot of fun to work on this over the past few years, collaborating with colleagues from completely different backgrounds: Angelika, Zsofia, Anton, Gerrit, Chris, Edwin and Hans.
The nice thing about this work is that I think you have to test as much of this new technology as possible yourself. And that is what I have been doing all these years. I consider myself an early adopter and a prosumer. That you sometimes have to take some clumsiness for granted is part of it. Gerda did suffer from this from time to time, although I have to say that in many cases she became an enthusiastic user of these novelties afterwards. I can't resist mentioning a few examples. Also because in some cases there is still a nice task for Creative Technology.

Video

In 1984, I bought my first video camera. Not a camcorder but a camera with separate recorder connected by a thick cable (figure 27). The batteries alone for those two devices were heavier and bulkier than a modern HD camcorder. It took an extra suitcase on holidays to transport this stuff. But I still have films from that era.

We also had a video editing system on the computer at the lab very early on. Our oldest video films were produced with it by Roger Bruis and me in the evening hours. Frequent saving of the result was important so as not to lose everything through the frequent crashes. Sound was hardly synchronous, and a simple 1 second transient took at least a minute to calculate. Now you do this sort of thing in real time and in HD quality on your iPhone.

FIGURE 27 Early adopter: video systeem met losse componenten

Navigation

When we went on sabbatical to Australia in 1999, the TomTom had yet to be invented and even the Aldi had no organisers with navigation on offer. There were already separate GPS receivers, though. Surely I was fascinated by these and managed to convince Gerda that without such a thing we would definitely

FIGURE 28 Early adopter: our GPS system in Australia

get lost in the Outback. Using a Garmin GPS tied to the mirror with a lace and scanned maps on the Libretto mini laptop on Gerda's lap, we thus created our own navigation system (figure 28).

But yes, if you also want to do 'geotagging' [81] and see if your iPhone with TomTom maps delivers the same navigation performance as the TomTom device itself, your car soon looks the same anyway (figure 29). There is still some development work to be done here. Fortunately, Gerda has long since resigned herself to the fact that I, as a former boy scout just love this modern form of map and compass.

Home automation

Home automation is a topic we are bound to hear a lot about in the coming years. Washing machines and dishwashers are by now mature products, but when it comes to fully automatic control of lights or household robots,

FIGURE 29 10 jaar later, geotagging [81] en iPhone versus TomTom

some progress is still needed. And as early adopters, we speak from experience. Automatic time switches that turn lights on and off at fixed times is, of course, technology from the last century. That's why I turned to a smarter system from Marmitek over the holidays a few years ago. It works with signals via the mains according to the so-called X-10 protocol. The system consists of a unit programmable from the PC (figuur 30), which can send signals to socket units, lamp units or built-in elements that can go behind a regular switch. At least if the pot in the wall is deep enough, otherwise it will cause a lot of grumbling. You can have the light switched on at sunset and off at any time between 23:00 and 24:00, for example. All units are independently programmable. Ideal for fooling burglars when you are on holiday. Even Gerda's requirement that everything should also be manually controllable is met by the system. Unfortunately, it is also sensitive to signals not coming from the central unit. Preferably when we go on holiday, the neighbours complain that at the oddest times in the middle of the night or during the day our light comes on. The problem was more or less solved by switching off all lights every hour in the programme at times when the light should at least not be on. We haven't heard any complaints since, but there is still room for improvement here too.

FIGURE 30 Home automation: programme for automatically switching your lights

Domestic robots

Finally, another example that shows that good mechatronic design is not necessarily obtained by adding a lot of electronics and software to the mechanics. Some time ago, when the vacuum cleaning robot Roomba stofzuigrobot (figuur 31)became available, we naturally wanted to test such a device, following our daughter's example. It is indeed a great robot. From the charging station, it moves around the room while roller-sweeping and vacuuming, using detectors to avoid obstacles and spinning in circles when serious soiling is detected. When it has had enough and the charging station is in sight, it even returns to its base automatically to recharge itself for the next round. Ideal for having the room vacuumed when you're not around. Then again, we might be too early adopter. Cords he loves which he tries to cram into his dust magazine. Our radiator hangs at a very slight angle. On the right, Roomba can fit right under it, but on the left he can't get under it anymore. So forget that unsupervised vacuuming, unless you completely remodel the room. Not to mention that story of a cat that was so startled by the Roomba that it defecated on the carpet. The poo was then neatly smeared across the carpet by the Roomba.

FIGURE 31 Robot vacuum cleaner Roomba and Robomop
Cords and grilles of a radiator pit still pose problems

If so, the Robomop, a kind of robotic duster, is a much simpler –and for smooth floors at least as effective– design. What's more, it works almost silently. The Robomop consists of a ball containing a motor that makes the ball roll within a cage to which a kind of 'Swiffer' is attached. The thing moves around the room at a speed a lot faster than the Roomba via a random pattern. It has hardly any sensors, but does a fine job of collecting dust. The simpler the better, although the Robomop will not remove bits of paper or biscuit crumbs. There is room for improvement here too.

iPads

A great example of Creative Technology is the iPad. The iPad combines advanced technology with extraordinary usability through an innovative interface. It is a challenge to develop these kinds of technological solutions in all kinds of areas. I have always defended the view that devices that require you to read the manual are actually not well designed. My environment has always been a testing ground for this kind of innovation. It is remarkable to see how my (in-law) parents aged 88-93 manage to use the iPad without much difficulty, even though my mother-in-law had never before touched a computer before. Now she enjoys receiving and sending e-mails, Googling and listening to radio through the iPad. And for small children, it is already no different. Even our 2-year-old granddaughter knows how to use the touch screen with no problem. Now that's what I call high tech, human touch!

FIGURE 32 For old ...

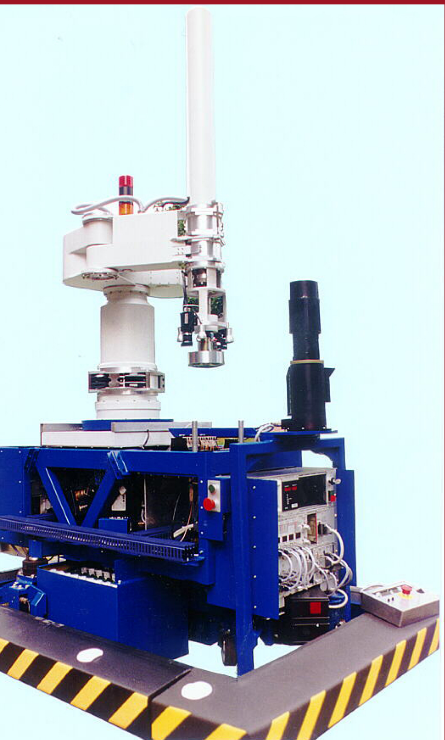
FIGURE 33
... and young

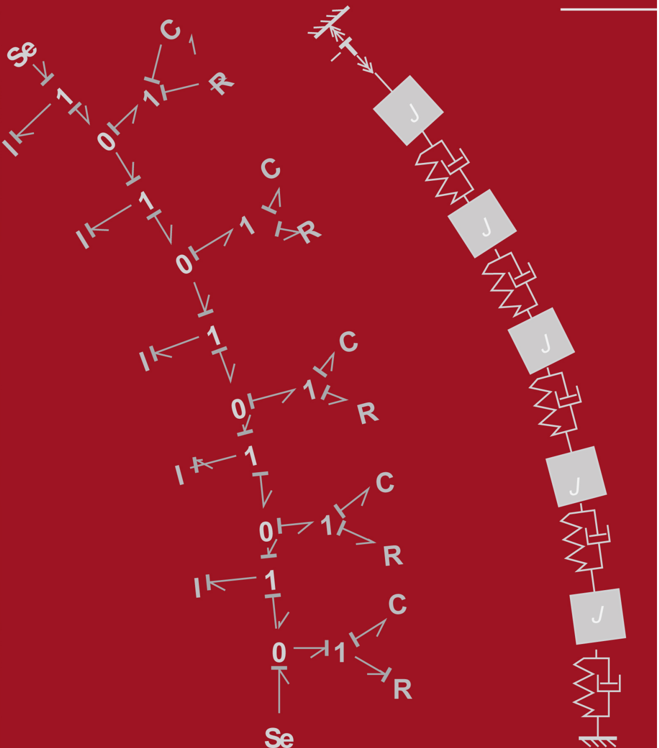
Dynamical Systems

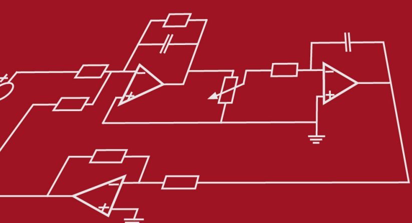
My curricular contribution to the Creative Technology programme is the first-year lecture ‘Dynamical Systems’. The challenge here is to present a technical subject in such a way that it can be understood even by students without a VWO background. The front page of the book ‘Dynamical Systems’ that I wrote for this purpose (see figure on page 38)) summarises much of my work over the past few years [41]. This front page figure shows how port-based modelling provides a surprising perspective on systems of completely different nature. For Creative Technology’s programming education, Angelika Mader wanted some flowers programmed and she asked me how I would go about making them move naturally. If you think about that, you can describe those flowers as a number of masses connected by springs. This is shown in the figure on the far right. If you want to calculate this system or find formulae, it is useful to draw an, even more abstract, bondgraph, shown in the middle. But almost the same bondgraph can also be used to describe the spring behaviour of the MART robot (figure 22). Finally, we can also simulate the behaviour of all these systems with the electrical circuit at the bottom left.

Dynamical Systems for Creative Technology

Job van Amerongen







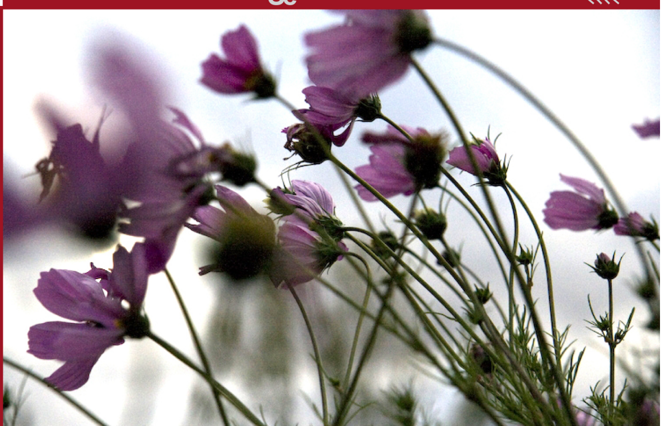


FIGURE 35 1) mechanical calculator at the ETV, 2) Thesis wordk: IBM-360 with 3) punch cards, 4) PDP-9, 5) first IBM-PC, 6) during PhD period: PDP-11, 7) 'laptop', 8) iMac

Looking back

Throughout my career, computers have played an important role. Much of the work would not have been possible without the tremendous developments in computers. The Computer History Museum (figure 36) in Mountain View, California, where we recently visited Renée regularly, actually features all the computers I have used during my career (figure 35). A visit to this museum is definitely recommended. Apart from the increased computing power, the price drop has also been crucial. The magnetic core memory of the PDP-9 computer (in the man-sized case on the right in figure 35-4) that I worked on during my graduate studies cost around € 50 000 for 16 kB. That's 3 billion € for 1GB. 1GB of working memory now costs on the order of € 50, a factor of 60 million cheaper. The possibilities of doing something with this intelligence today are almost endless. What is needed is the creativity and knowledge to do meaningful, useful and fun things with this.

FIGURE 36 Computer History Museum [79]

I have personally enjoyed being at the forefront of both hardware and software all these years. I think it is also part of a scientist's curiosity to experiment with the latest possibilities in your field. This lives at odds with standardisation that administrators or 'officials' often pursue. A standard is always based on past technology and inhibits 'progress'. And that cannot be stopped. Of course, standardisation is necessary in many cases, but initiatives to explore new possibilities should be encouraged and not suppressed at a university. The world

wide web is the best example of this. It is a source for creative technology.
As dean, I once wrote another letter that the faculty of electrical engineering would not care about the regulation by the voard of the UT that Gopher should be the internet standard for the UT. The world wide web was already on the rise by then and Gopher had become totally obscure within a year of that regulation.

Smart Grids

It is interesting to see how some topics I have dealt with in the past are becoming very relevant again. If we are going to realise alternative forms of electricity generation on a large scale, using wind turbines, solar cells, or CHP boilers with combined heat and power, and also combine that with increasing consumption, e.g. of electric cars, we will need techniques similar to those I used when I graduated. More than so far, we will need to ensure that consumption is adjusted to the production possibilities at any given time. Maybe charging those electric car batteries or cooling the freezer can wait a while if there is not enough production capacity. That car could even feed energy back to the grid if there is too little production capacity or a power failure. Nissan recently reported experiments where the Nissan Leaf can power the house for two days in such a case. Again, dynamics, i.e. what has happened in the past and what we expect for the near future, plays an important role. If we want to maintain a reliable electricity supply, with all kinds of those not always reliable sources, then, besides economic factors, a good technical infrastructure of the overall *system* plays an important role. Electricity networks that are capable of this are called *Smart Grids*. The problem of optimising electricity generation and power-frequency control, which I worked on during my graduation, comes all the way back to optimising Smart Grids. The problem is more complex than back then, but because over the years the computing power and flexibility of computers has increased enormously, we are now able to realise this kind of system as well.
A real systems approach is needed to optimally combine small-scale generation at private homes, via combined heat and power plants and solar cells and via wind turbines with hydroelectric plants in Norway, so that reliability and quality of energy supply is maintained in the process.

The Future

As with the automatic highway, where the motorist and his car become part of a system where others or computers determine the speed, so too with Smart Grids it will be decided centrally to what temperature and when the freezer should cool, when the (electric) car should be allowed to charge or perhaps even deliver charge back to the grid. To switch those devices at the homes of users, those devices will need to be connected to the internet. In the future, many more devices and 'things' will be connected to the internet. We will then speak of the 'internet of things'. And that completes the circle: the 'Internet of things' is Creative Technology.
Mechatronics will remain an important field in the years to come. Increasing computing power, energy-efficient and small electronics will increasingly play a role complementing or even completely replacing mechanical structures. Solid-state memories will replace tapes and hard disks just as the mechanical typewriter can be replaced by a (virtual) keyboard. Printed matter will be replaced by e-paper. When you get used to it, the newspaper or a magazine reads more pleasantly on an iPad than on paper. Therefore, an electronic version of this booklet is also available, of course, with additional features, such as direct viewing of (part of) the references, colleges and videos [80], [81].
The challenge for Creative Technology is to use the technical capabilities that are already there and will be there in the future in systems that are especially mindful of users. Technology will increasingly become invisible as systems are designed from a user perspective. ICT systems, alongside robotic systems, will start to make a significant contribution to allowing older people to live independently for longer.

When testing the adaptive autopilot at the time, a lot of attention was paid to the user interface of the control panel. I believe this is very important. If it is necessary to study the manual of a device more than once or even at all, you can say that the device was actually designed wrong. Creative technology and smart screens can still do a lot here. Interfaces for computers can take on a completely different look, as in the case of the Nabaztag, for example.
Closer to the computer, but also a device that can be used and operated instantly without a manual, is the iPad. With the right apps, the iPad is a universal user interface. The iPad or iPhone is as easily a remote for audio and video equipment [84], as it is for controlling a 'quadrikopter', such as the Parrot Drone [85].

FIGURE 37
Nabaztag

The Nabaztag is a Miffy-like rabbit that can communicate with conspecifics (and therefore their owners) anywhere in the world by transmitting the position of its ears. Furthermore, the Nabaztag can read out e-mails or e-books or play internet radio stations and forwarded messages. The Nabaztag is an example of the internet of things, where the most unlikely objects will soon be connected to the internet.

Many of these developments I will have to leave to my successors and to the trained PhD students and graduates, but I hope to still actively contribute to them myself.
From the enumeration of the 'almost' working innovative things at our house, it will be clear that I can still be busy with that at least in the coming time. In addition, I hope to supervise a few more PhD students up to the doctoral degree and will remain active in CreaTe education. One way or another, I also hope to be able to make use of student input for a while yet. These are all smart people. And I have always tried to learn as much from the students as they do from me. In addition, I want to get involved in writing one or more books that support 20-sim in collaboration with Controllab Products. Travelling we have done together regularly, so that will also remain an activity. For my hobby of photography, I also hope to get some more time. There are also a couple of unread books waiting on developing apps for the iPhone and iPad to be read and put into practice. I realise this is actually too much already.
There is still plenty to look forward to. And what better way to illustrate this than with the sweeping view of my old room on floor 8 of the Hogekamp in autumn colours (figure 38). The library indicates that I am not saying goodbye to science, the forest makes it clear that there are also lots of other beautiful and still unknown things to look forward to.

FIGURE 38 View from floor 8 of the Hogekamp: Lots of great things to look forward to

THANK YOU

Looking back over all those years, a lot has happened and quite a lot has been achieved. But you don't do something like this alone. I have always greatly appreciated the Dutch construction of a professional group with a group interest. I would particularly like to mention Peter Breedveld, Jan Broenink, Edwin Dertien, Angelika Mader, Gerben te Riet o.g. Scholten, Marcel Schwirtz, Theo de Vries and Alfred de Vries. And also the former colleagues, Andr Bakkers, Peter Löhnberg, Gerrit Strecker, Rien Koster, Herman Soemers and Roger Bruis, who died far too young. You were all very different and that is precisely what made the collaboration so interesting. Of course, my thanks also go to the PhD students [44]—who I cannot mention all of you by name here.

Control Engineering has always been popular with students. That is, of course, because it is a fascinating field, but also because it is just a very sociable group. And in that, the secretariat plays an important role. Jolanda Boelema and especially Carla Gouw who was my secretary for almost 10 years: many thanks for these contributions to the atmosphere and for the great support I always received.

Stefano, you took over the gavel from me two years ago. With that, the research is moving in a slightly different direction and that's a good thing. It would not be good if everything stayed as it was. You have already hired two enthusiastic new collaborators, Raffaella Carloni and Sarthak Misra, who will help out in the robotics and medical robotics research. Stefano and also everyone else, I will be happy to visit regularly in the near future and you can always call on me. If I like it, I might say yes. But I promise not to get in your way.

I also thank all my colleagues in Electrical Engineering who made my work, then as dean and more recently as department chair, so enjoyable. It was a pleasure to discuss the ups and downs of Electrical Engineering with you once a month over lunch. The cooperation with all the people in the faculty office and with colleagues in the MT, especially Ton Mouthaan, first as education dean and later as dean, has always been very pleasant. Thank you all for that.

My parents who are not here because it would all be too tiring, I thank them for the support they have always given me.

I thank my daughters, Renée and Shoshanna, for sharing in the joys and burdens of my work. Our holiday destinations were often determined by the conferences I had to attend, but they did take us to America, Australia and Japan. So it wasn't that bad. The lively discussions we often had during meals (and still often via Skype or FaceTime) kept us all on our toes. Thanks for that.

Duo job

I have always said that together with Gerda, I had a duo job. With your hobby of 'cooking', you not only ensured that I enjoyed going home every day to enjoy an often new dish [86]. Many foreign visitors to the lab also enjoyed it. You have always helped me with *everything*. Few papers of mine went out the door that you did not read at least once. That was true for papers or visitation reports, but also for Ou courses, for example, where you often typed the formulas. If the secretary was ill, during the organisation of a congress, you jumped in, so that when you acted as photographer during the congress, you knew all the speakers by name like no one else. I wouldn't have been able to do all this without you.

Thank you so much for that!

FIGURE 39 Dual job: Gerda helps organise the 2002 Congress

FIGURE 40 Duo job

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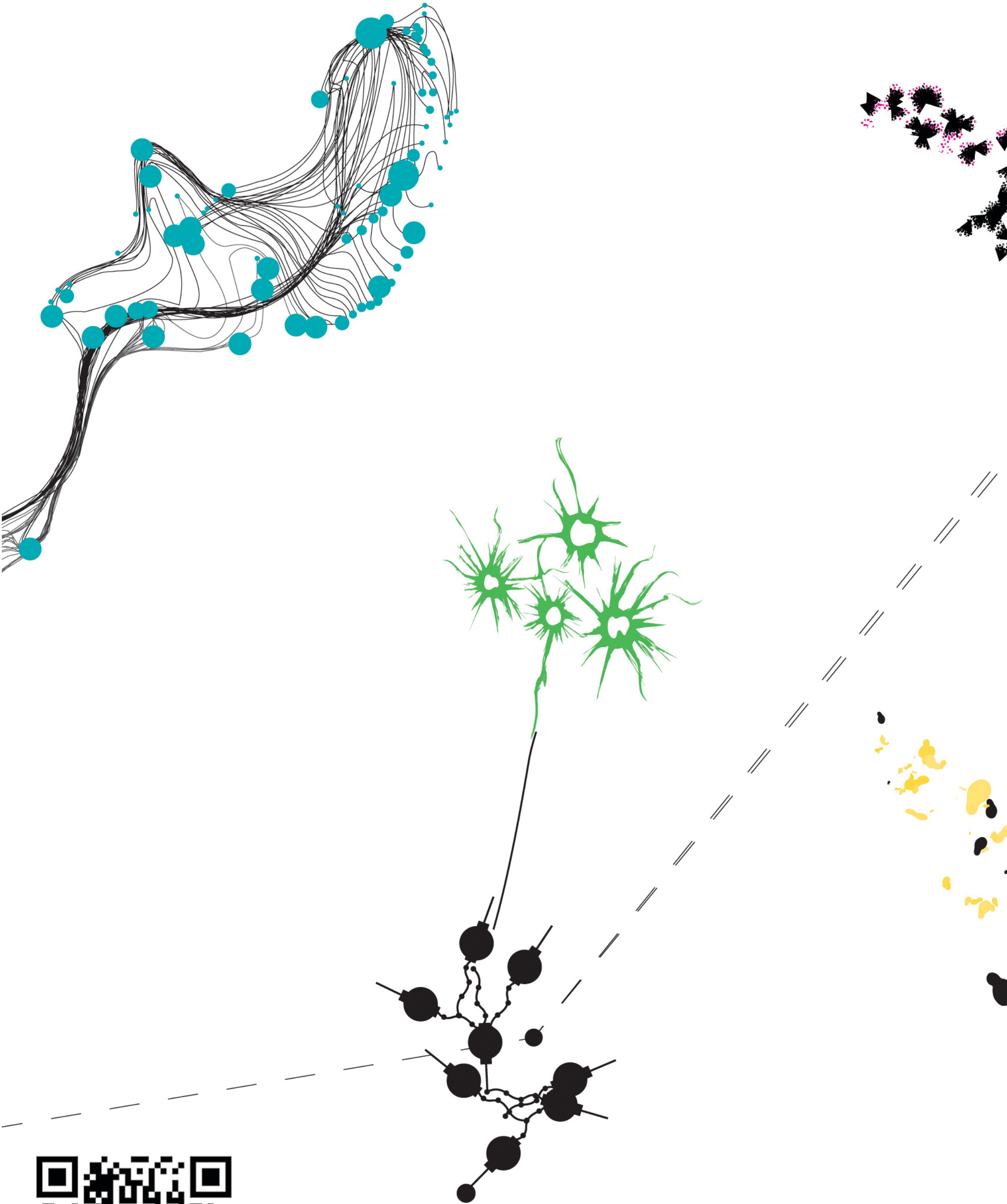

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