Mechatronics Team: Mission and Members

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

The Mechatronics Team is an inter-departmental work group to provide and promote advanced research and education on the inter-disciplinary field of Mechatronics and Microsystems

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Current Research Activities at the Physical Electronics Laboratory (PEL)

Interfacing Neurons and Silicon

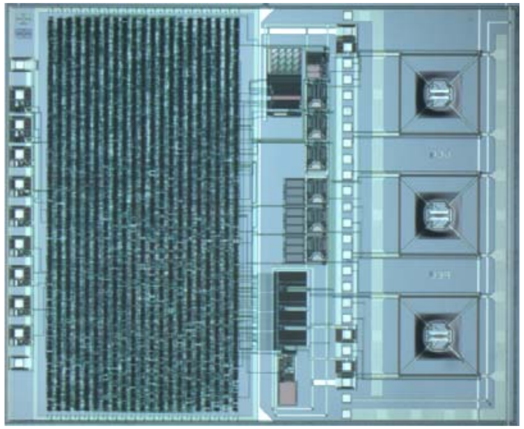
- Electrode arrays for extra-cellular recording of cell activity
- Growth control and patterning

➔ Neurophysiology, drug screening

Biosensors

- Cantilever-based immunosensor (resonant and static mode)
- Microfluidic polymer packaging

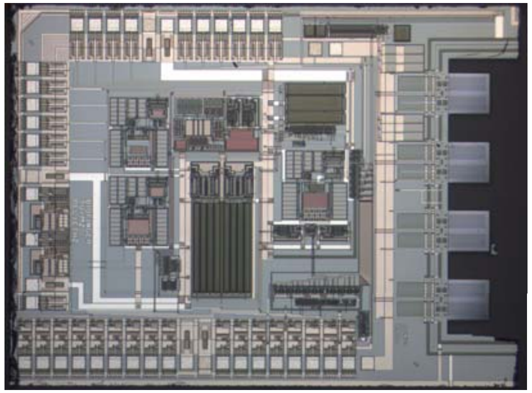
➔ Medical diagnostics, drug screening



Gas sensor array with three PID-controlled microhotplates.

Core Technology:

CMOS-based MEMS with Integrated Circuitry



Biosensor chip with four independent cantilevers sensing specific biomolecule binding.

Chemical Sensors

- Capacitive, calorimetric, cantilever-based, and resisitve gas sensors
- Programmable microhotplate arrays

➔ Environmental, house-hold, industrial monitoring

Other Areas

- CMOS circuitry for MEMS: low-noise amplifiers, ADCs, DACs, I^2C interfaces
- Tactile sensors for medical applications
- Magnetic sensors: vertical Hall
- Packaging, flip-chip bonding

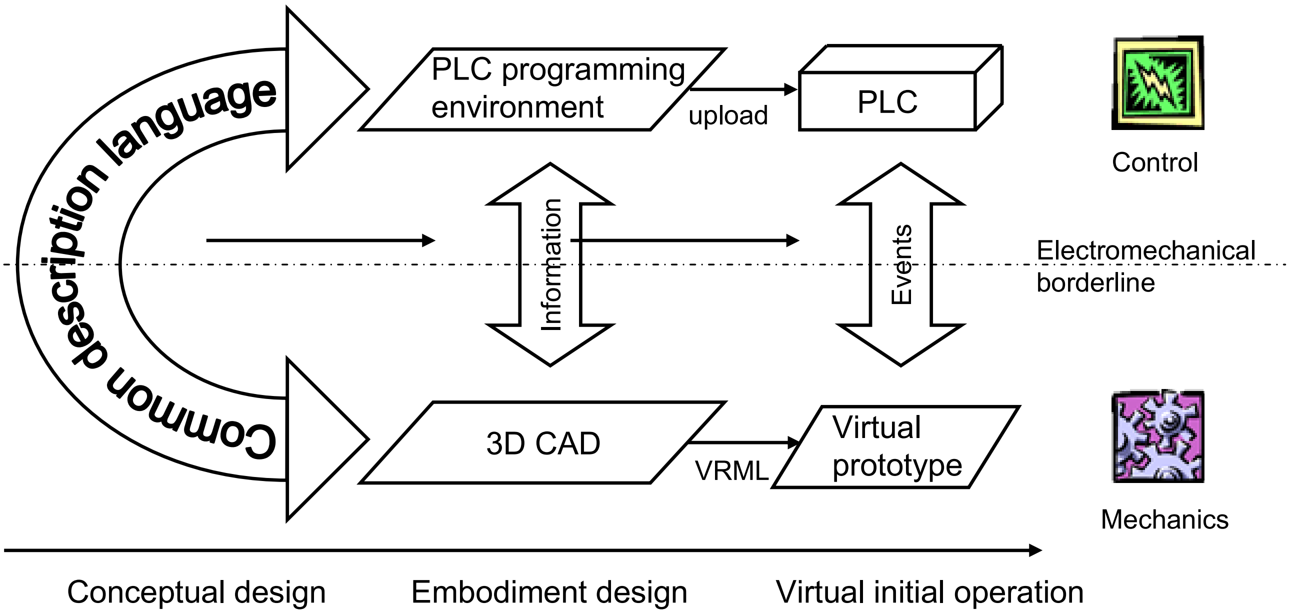
EVA: Early Virtual mAchine

Abstract

The development of the concepts of the Early Virtual mAchine was initiated by the experiences of the virtual machine project, where a virtual initial operation was enabled. A serial design process (first mechanical layout, then software development) and a poor information exchange between the mechanical and control engineers were detected. In order to reduce the development time and avoid errors in the virtual initial operation a concurrent interdisciplinary development process for PLC controlled mechatronic systems was shaped as shown in the figure. Both disciplines work synchronised from the very first function structure in the conceptual design phase to the virtual initial operation after the embodiment design phase.

Keywords

Mechatronics, concurrent engineering, PLC (Programmable Logic Controller)



Concept

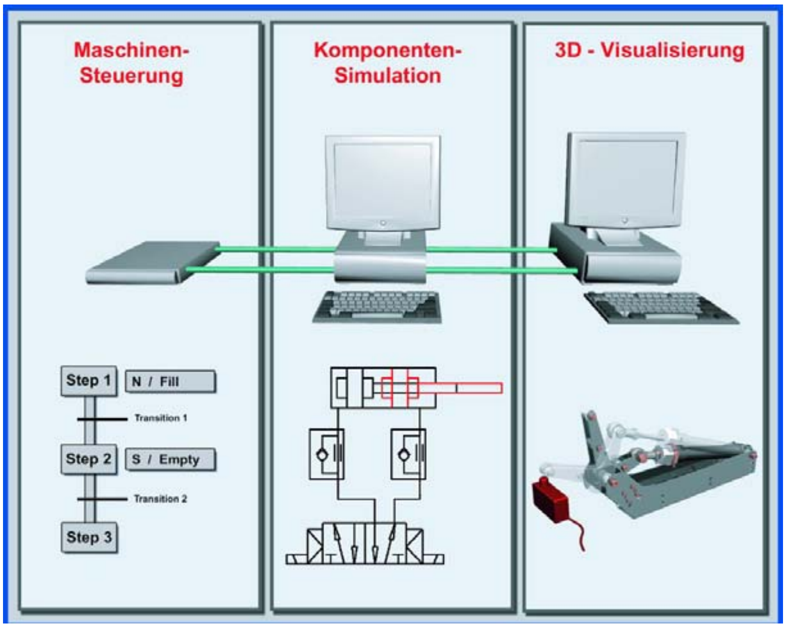
A common description language is used by the control and mechanical engineers to document the concept of the mechatronic system. A bridge to the CAD system and the PLC programming environment does initiate the embodiment design phase for both disciplines at the same time. An assembly tree for the mechanical engineer and a sequence of operations for the control engineer is derived from the common description language. The interdisciplinary information (like data about actuators and sensors) can be extracted from the common description language and will be shared and updated during the embodiment design process. The interdisciplinary information is used to build the event simulation and to connect the virtual mechanics with the real control, which results in the virtual machine.

ETH Zentrum für Produkt-Entwicklung
Prof. Dr. Markus Meier

The Virtual Machine

Abstract:
The virtual machine permits a functional initial operation on the basis of pure digital data. Furthermore, it offers new perspectives for training, service and sales. The modern visualization and simulation possibilities help to understand complex sequences and coherences faster and indicate potential fields of problems. The development time as well as the time duration for training and sales processes of a product can be reduced and related cost advantages can be obtained. Moreover, additional advantages with the digital data are feasible, as for example consistent data administration, fast update possibilities, location distribution, variant configuration, etc.

Keywords
Mechatronic, signal simulation, sensor, actuator, virtual reality, realtime, system coupling, fieldbus



Concept

The fundamental idea of the concept is based in the linkage of the three areas: machine control, simulation and visualization. The control communicates in real time with the simulation which calculates signal information and also the position and location of the actuators. The current positions or conditions of all sensors and actuators are passed to a virtual reality software which visualizes the corresponding movements and sequences. The viewer can choose his viewpoint during the simulation run and recognize possible collisions and mistakes during program expiration. Furthermore, operational faults can be checked by the possibilities of interaction of the simulation/visualization software and disruptions can be simulated.

The complete concept is oriented on practical use in companies and tries to maintain the established mode of operation within the enterprise. This is achieved by the integration of the real machine control and a signal simulation tool that is simple to handle. In addition, the visualization model derives from the 3D CAD; yet this fact represents another payback of this technology. Once the model is constructed, training and presentation models can be derived regarding the corresponding functionality for the respective application case.

PIOPS – Prozessintegrierte Optimierung von Produktstrukturen

Kurzbeschreibung:

Konzipierung und Entwicklung strukturierter Produktfamilien

Typ:	KTI-Projekt - KTS 6070.1		
Industriepartner:	Agathon AG ESEC SA	Intelliact AG SIG Pack Systems AG	Step-Tec AG Studer AG
Dauer	1.11.2002 – 1.11.2004		
Verantwortlich	Rok Sekolec, Aurel Kunz		
Informationen	www.piops.ethz.ch		

Umfeld

Im Rahmen des Projektes PiOPS wird eine Methodik zur Entwicklung strukturierter, modularer Produktfamilien mit Mechanik, Elektrotechnik und Software als integrale Komponenten konzipiert. Die Optimierung soll die Anforderungen der verschiedenen Unternehmensprozesse wie Entwicklung, Fertigung, Montage, Verkauf, Service gesamtheitlich berücksichtigen. Da in der frühen Phase der Produktentwicklung über 70% der zukünftigen Kosten eines Produktes festgelegt werden, soll diese Optimierung bereits in diesem frühen Prozessabschnitt der Produktentwicklung erfolgen.

Inhalt der Arbeit

Abbildung 1 zeigt die Schritte, die in der Produktstrukturierung im Kontext einer Produktkonzeption durchlaufen werden.

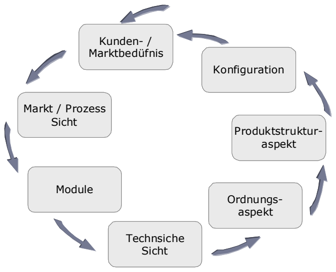


Abbildung 1: Schritte der Produktstrukturierung im Kontext der Produktkonzeption

Kunden-/Marktbedürfnis: Grundlage ist die Klärung der Kunden-/Marktbedürfnisse. Zielsetzung ist die Positionierung des künftigen Produktes im Markt unter Berücksichtigung strategischer Aspekte und der Konkurrenzanalyse sowie die Fokussierung auf die zu bedienenden Kundengruppen.

Markt-/Prozess Sicht: Ausgehend von den fokussierten Marktsegmenten und den damit verbundenen Produktanforderungen, wird die Markt-/Prozess Sicht beschrieben. Dabei wird unterschieden zwischen marktseitigen Produktanforderungen sowie unternehmensinternen Anforderungen die aus Unternehmensprozessen resultieren können. Zielsetzung ist eine strukturierte Beschreibung der Marktanforderungen. Modelliert wird die Markt-/Prozess Sicht über eine sog. Merkmalsbeschreibung (Merkmal + Ausprägung), die einfache Funktions-, Bedienungs- oder Leistungsbegriffe für das Produkt darstellen.

Module: In einer ersten groben Strukturierung wird das Produkt basierend auf der Funktionsstruktur in Module gegliedert. Neben dieser reinen funktionellen Gliederung sind auch unternehmensexterne (z.B. Gesetze, Vorschriften, Technologien, Kundenwünsche, usw.) sowie unternehmensinterne (künftige geplante Erweiterungen, Randbedingungen aus Montage oder Fertigung, usw.) Faktoren zu berücksichtigen. Die Funktionalität der Module sowie die Modulaufgabe im Gesamtsystem wird beschrieben und Entscheidungen zur Modulbildung werden dokumentiert.

Technische Sicht: In einem ersten Schritt werden die Module über eine Merkmalsbeschreibung beschrieben. Auf diese Art kann die Variabilität (Variation der Komponenten als auch Wahlmöglichkeiten) der Module sehr einfachen und flexibel beschrieben werden, unabhängig von konkreten, technischen Lösungen und Strukturen.

Ordnungsaspekt: Im Ordnungsaspekt werden die Voraussetzungen für den Aufbau einer geeigneten Produktstruktur geschaffen, die ihrerseits innerhalb des Produktstrukturaspektes nach den Kriterien der einzelnen Prozesse gestaltet wird. Zu diesem Zweck steht im Ordnungsaspekt die Analyse, qualitative Bewertung und Optimierung der Variabilität der Technischen Sicht im Mittelpunkt. Hilfsmittel hierzu bildet ein Matrizensystem aus Korrelations- und ggf. Verträglichkeitsmatrix (Abbildung 2).

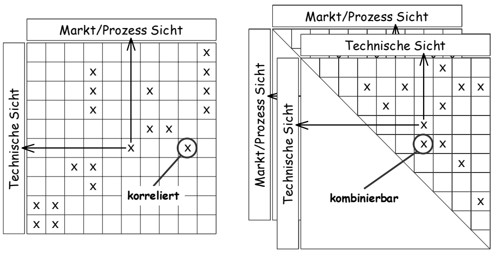


Abbildung 2: Matrizen im Ordnungsaspekt

Produktstrukturaspekt: Im Produktstrukturaspekt wird ausgehend von der Modulstruktur und der Variantenbeschreibung aus dem Ordnungsaspekt die Produktstruktur erstellt. Zielsetzung ist die optimale Handhabung der Produktstruktur in den verschiedenen Unternehmensprozessen. Im Mittelpunkt stehen dabei neben der Modularisierung häufig auch Standardisierungsmassnahmen (Teilefamilienbildung, Gleichteile- & Wiederholteileverwendung, Normung, ...), um die Teilevielfalt gering zu halten und Skaleneffekte zu realisieren

Konfiguration: Im letzten Schritt wird die Produktstruktur mit zusätzlichem Konfigurationswissen ergänzt, um die nötigen Voraussetzungen zu schaffen, die Produktfamilie in einem Konfigurationssystem abzubilden und zu nutzen

IMRT Institut für Mess- und Regeltechnik
Measurement and Control Laboratory

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

The Measurement and Control Laboratory of the Swiss Federal Institute of Technology in Zurich

Introduction

What is control? – The audio edition of the Merriam-Webster's Collegiate Dictionary and Thesaurus defines the verb «control» as follows: «to exercise restraining or directing influence over (something).» Example: «cruise control: an electronic device in an automobile that controls the throttle so as to maintain a constant speed.» – Please note that this short definition already introduces both feedback control and feedforward control! The IMRT logo symbolically visualizes both of these features of a control system.

IMRT

At the IMRT, we pursue a model-based approach to the optimization and the control of mechatronic, thermotronic, aerotronic, and economic systems.

Teaching

We are responsible for teaching control in the Department of Mechanical and Process Engineering. The IMRT teaches the required introductory course Linear Control Systems, the web-based short course Introduction to Matlab, and laboratory experiments on dynamics and control. For students taking a major or a minor in automatic control, a rather diversified collection of advanced control courses are offered: Optimal Control, Robust Control, Digital Control, Adaptive Control, and Stochastic Systems. Furthermore, three courses in mathematical modeling of dynamic systems covering system dynamics in general and engine dynamics and vehicle dynamics in particular are offered. An additional «hardware-in-the-loop» course allows the students to test their expertise in control design using Matlab and Simulink on a PC which is interfaced with a real plant such as an inverted pendulum.

Research

The focus of our research lies on modern control of automobiles, unmanned flying objects, heatpumps, fuel cells, finance, and biology. We build mathematical models of engines, transmissions, and drivelines of automobiles, fuel cells, heatpumps used in space heating systems, of helicopters and winged aircraft, of financial systems such as pension funds and stock markets, and of biological systems such as the human brain. The validation of our mathematical models and control designs for the technical systems is performed using real hardware: We have test benches for automotive engines, heatpumps, model helicopters, winged model aircraft, and fuel cells. We closely cooperate with industrial partners in Switzerland, Europe and overseas which provide financial support and technical stimulus.

Special Equipment

Besides the necessary standard equipment, the hardware available enables the investigation of highly dynamic behavior of the various systems. The IMRT operates four medium-size engine test cells (two static, two dynamic) and cutting-edge emission measuring equipment (all species, sampling times less than 10 ms). Various engine management systems, from basic research system to production-type ECU with bypass possibilities, allow us to choose the most adequate way to control the system under test.

A dynamic test bench for brine-to-water heatpumps allows the emulation of the thermal behavior of a virtual house as well as that of a fictitious earth probe for arbitrary weather situations, thus enabling reproducible tests.

Staff

The Measurement and Control Laboratory is staffed with two professors, three senior research associates, occasional postdocs, some twenty doctoral students, three mechatronics engineers, and two secretaries. We are lucky to receive further support from students working part-time who perform various tasks for us, both in teaching and in research.

Hans P. Geering joined the faculty of ETH on October 1, 1979. He is a Professor of Automatic Control and Mechatronics in the Department of Mechanical and Process Engineering and in the Measurement and Control Laboratory.

Professor Geering was born on June 7, 1942. He is a citizen of Switzerland. He received his Dipl.-Ing. degree from the Department of Electrical Engineering of ETH Zurich and his Ph.D. degree from the Department of Electrical Engineering of the Massachusetts Institute of Technology. His Ph.D. thesis was supervised by Professor Michael Athans.

He teaches the required course Linear Control Systems and the advanced control courses Optimal Control, Robust Control, and Stochastic Systems in the Department of Mechanical and Process Engineering.

In his research, Professor Geering focuses on optimal control and robust control with the following fields of applications: navigation and control of unmanned aerial vehicles, model-predictive control of space heating systems with heatpumps, stochastic control in the area of finance, and model-based robust control of automotive engines.

Professor Geering is a Fellow of the IEEE and an Associate Fellow of the AIAA.

Lino Guzzella was born in Zurich, Switzerland in 1957. He received the Diploma in Mechanical Engineering in 1981 and the Dr. sc. techn. degree in Control Engineering in 1986 from the Swiss Federal Institute of Technology (ETH) Zurich.

From 1987 to 1989 he was with the R&D Department of Sulzer Bros. in Winterthur, Switzerland. From 1989 to 1991 he was an Assistant Professor for Automatic Control in the Electrical Engineering Department of ETH Zurich. He then joined Hilti R&D, Liechtenstein where he was the head of the Mechatronics Department from 1992 to 1993.

Lino Guzzella was appointed Assistant Professor of Engine Electronics at the Energy Technology Laboratory of ETH in 1993. Upon his promotion to Associate Professor in 1996, he founded the Engine Systems Laboratory which in October 2000 was integrated within the Measurement and Control Laboratory, all within the Department of Mechanical and Process Engineering.

His current research interests include the modeling, control, and model-based optimization of mechatronic and energy systems using nonlinear and hybrid approaches. The primary aim of his research projects is to contribute towards the reduction of fuel consumption and of engine emissions levels. In teaching, Lino Guzzella is especially interested in fostering cooperative and project-oriented learning techniques.

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PALOS (Part-Load Optimized Propulsion System)

The global need to reduce carbon dioxide emissions and the local need to reduce pollutant emissions force the development of very efficient engines with virtually no pollutants. As the efficiency of a combustion engine decreases substantially at low loads, this project focuses on the enhancement of part-load efficiency.

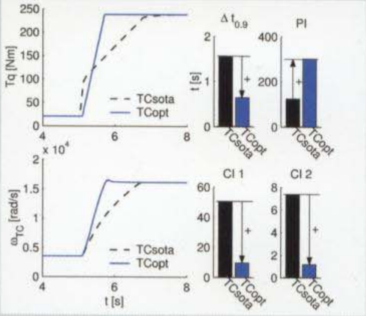
Downsizing & Supercharging Concept

The most obvious step to improve part-load efficiency of naturally aspirated spark ignition engines is to reduce the engine displacement (downsizing). In order to achieve the same torque with the downsized engine the intake air pressure has to be raised (supercharging). Among the most common devices for supercharging engines are the turbocharger and the so-called pressure-wave supercharger (PWS). These two chargers are being investigated and optimized with regard to both theory, based on a mathematical model, and practice, building up an engine testbench.

Turbocharged SI engine on a dynamic testbench

Whereas the short response time and the ability of high boosting even at low mass flows could be arguments in favour of the use of a pressure-wave supercharger, the major problem is the appearance of unwanted exhaust gas recirculation (EGR) since fresh air and exhaust gases are not separated within the cell wheel. A control strategy meeting these concerns is being derived.

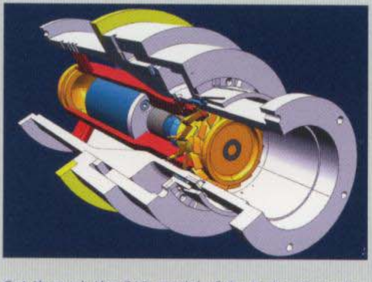
Turbocharged engines suffer from the fact that the runner has to speed up in order to produce the desired boost pressure. This leads to a delayed torque build-up (turbo lag). Several devices are known to tackle this problem, but they all entail the cost of extra hardware. In the ongoing project the longitudinal behavior (agility) of a vehicle with a turbocharged engine is improved by applying optimized control strategies. A model not only depicting the steady state but also the dynamic behavior has been developed. For the quantification of the agility a new cost functional and a test case have been derived. These tools are now used for a model-based optimization. The following figure contrasts a state-of-the-art strategy (TCsota) with an optimized strategy (TCopt).



Optimized control strategy for a turbocharged SI engine (power index PI, comfort index CI)

LORIS

In stoichiometrically operated SI engines load is controlled by throttling the intake air. This leads to high throttling losses at part-load. To recuperate these losses a system with a turbo-generator as the core component has been designed and tested within an interdisciplinary student project. Its main focus was on turbine design and control. In ongoing work a control strategy is being developed to maximize energy recuperation and achieve similar dynamic responses to those available from the conventional system. On an engine test rig the control strategy can be tested and the amount of recuperated energy over a standard engine cycle can be measured.



Cut through the CAD model of the turbo-generator

Optimal Control of Engine Auxiliaries

The improved capacity of new electrical systems in passenger cars enables the «electrification» of different auxiliary devices, such as coolant pump, fan, air conditioning systems or supplementary heater. Since the electrical components are no longer coupled directly with the engine, they can be operated independently of the engine speed (additional degree of freedom).

In this research project, optimal control strategies for such electrical auxiliaries are developed in order to improve passenger comfort and safety, reduce fuel consumption, lower pollutant emissions, and extend engine lifetime.

$$x^o(t_a) = x_a$$
$$\dot{x}^o(t) = f(x^o(t), u^o(t), t) \qquad \forall\, t \in [t_a, t_b]$$
$$J(u) = K(x^o(t_b), t_b) + \int_{t_a}^{t_b} L(x^o(t), u^o(t), t)\, dt$$

$$\dot{x}^o(t) = \nabla_\lambda H_{|o} = f(x^o(t), u^o(t), t)$$
$$x^o(t_a) = x_a$$
$$\dot{\lambda}^o(t) = -\nabla_x H_{|o} = -\nabla_x L(x^o(t), u^o(t), t) - \left[\frac{\partial f}{\partial x}(x^o(t), u^o(t), t)\right]^T \lambda^o(t)$$
$$\lambda^o(t_b) = \nabla_x K(x^o(t_b), t_b)$$
$$H(x^o(t), u^o(t), t, \lambda^o(t)) \leq H(x^o(t), u, t, \lambda^o(t))$$

Mathematical description of an optimal control problem

Modeling of Engine Systems

Control-Oriented Model of NO Emissions from Combustion Engines

From the control-oriented point of view, the plant – the engine – has ever more inputs for which meaningful control laws have to be developed to ensure that the output of the plant fulfills certain requirements, such as good drivability and compliance with emission legislation. Due to the increased number of inputs the identification of the input-output transfer function has grown expensive and time-consuming. Therefore the automotive industry uses models of the engine to reduce the amount of expensive testing. This project focuses on the development of a physics-based, control-oriented model of NO emissions for spark-ignited engines. Submodels include the estimation of the transient cylinder pressure, the temperature of the burned gas in the cylinder, and the process of NO formation.

Wall-Wetting Modeling and Compensation

For the catalytic converter to work properly, the air-to-fuel ratio has to be as close as possible to stoichiometric. This is especially difficult to achieve during large transients, such as throttle tip-in or tip-out (as they occur during gear changes). These problems are caused by dynamics such as delays, manifold filling or emptying, and the wall-wetting phenomenon. The wall film is the part of the injected fuel remaining in the intake duct near the valves which evaporates very slowly. The control of the wall-wetting system is the worst problem due to its nonlinearity and the fact that no direct measurements are possible. A detailed model of the system is thus required for the prediction of its behavior. This model can be obtained by studying the evaporation of the fuel with the help of the Reynolds analogy.

Catalytic Converter

Very strict emission regulations of automotive engines force the use of the three-way catalytic converter to full capacity. The same regulations demand that the on-board diagnosis system be able to accurately monitor the catalytic converter's performance. This performance, however, is strongly dependent on the system's state, especially the state of the oxygen storage level. Since neither the performance nor the oxygen storage capacity can be measured directly, appropriate models have to be derived which estimate the required quantities from the sensor information up- and downstream of the catalytic converter. Based on these models a controller is developed which optimizes the catalytic converter's performance by an appropriate adjustment of the air-to-fuel ratio of the exhaust gas.

Fuel Cells

Smart Controllers for Fuel Cell Systems

In the past, Polymer Electrolyte Fuel Cells (PEFC) were exclusively used in aerospace or military applications. The demands on PEFCs in those fields differ greatly from those in automotive applications, where the pressure of costs is much more severe. Furthermore, the reductions of volume and weight are at the center of ongoing research. Most often these demands can only be satisfied at the expense of efficiency or other parameters. Here control tools can help to reduce these losses to a minimum. In a direct hydrogen fuel cell system several components need to be regulated. The reactant gases (hydrogen and air) must be supplied at the required pressure, flow rate, temperature, and humidity. The cooling subsystem has to guarantee an adequate cooling of the fuel cell stack and to ensure that the temperature gradient across the stack remains small. Several of theses parameters interact, e.g., an increase in mass flow translates into a higher pressure if the valve position is kept unchanged. Although experiments at our 5 kW fuel cell testbench have proven that the fuel cell acts as a sufficient damping element and that PI controllers provide satisfactory results, they also showed that state-based controllers decouple pressure and mass flow more effectively and exhibit a superior behavior with regard to response time and to deviations from the setpoint. Smart controllers thus eliminate the need for heavy buffer batteries to compensate the lag of the supply system.

Hy.Power

Our laboratory worked intensively on the realization of the experimental vehicle Hy.Power, which is a fuel cell powered electric vehicle assisted by supercapacitor storage. The powertrain in this hybrid vehicle is used to explore the performance of new materials and system architectures, hence yielding insights for further developments. The Hy.Power vehicle is part of an ongoing collaboration between the Paul Scherrer Institute (PSI, Switzerland), the Swiss Federal Institute of Technology (ETHZ), and several industrial partners. It is equipped with a fuel cell system with a nominal power of 48 kW and with supercapacitors that have a storage capacity of 360 Wh. Extensive tests have been performed on a dynamometer and on the road to investigate the operating ability. The highlights of these tests were the successful trial runs across the Simplon Pass in the Swiss Alps in January 2002.

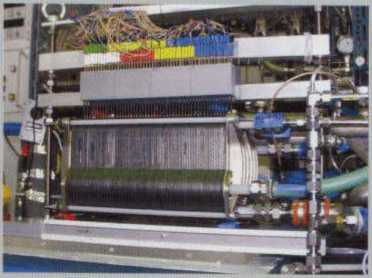
PowerPac

In addition, the Measurement and Control Laboratory and the Paul Scherrer Institute cooperate in the development of PowerPac, a hydrogen-powered portable and mobile power source. Its main advantage over conventional technologies (batteries or generator with a combustion engine) is its perfectly clean and much more quiet operation allowing indoor use without the energy limitation inherent to batteries. The main control task is to design an embedded and perfectly autonomous controller for this system. Among the desired features are easy and safe operation in a compact and light packaging with an information display for the user. An integrated recorder allows both on-line and off-line data analysis providing precious information for the development phase of this project.

Pac-Car

The PowerPac technology was adapted to power the Pac-Car vehicle which will compete in the Shell Eco-marathon. The goal of this annual event is to race a car with the least fuel consumption on some 25 km at a minimum average speed of 30 km/h. Up to now, the fuels allowed in this competition were gasoline, diesel, and LPG. On the special request of our laboratory, Shell has admitted hydrogen as well, starting in 2003. The ultra-light race vehicle is powered by a 600 W polymer electrolyte fuel cell stack which drives the traction electric motors. The hydrogen is stored in a metal hydride tank.

Fuel Reformers



One of the main challenges which need to be solved is the establishment of a satisfactory hydrogen supply infrastructure. Here, fuel reformers are considered to be a feasible alternative. Fuel reformers use a high-temperature catalytic process to convert liquid fuels, such as gasoline, into a hydrogen-rich reformate gas. For automotive applications, auto-thermal reforming is the most promising technique. Here, fuel is combined with a precisely controlled mixture of water and air to produce the reformate gas. The advantage of auto-thermal reforming over other techniques is that no external heating is required and reasonably fast transient responses can be achieved. However, the precise control of feed rates is crucial to the achievement of high efficiencies and the minimization of unwanted by-products that could poison the fuel cells. This applies in particular to the fast transient loads typically occurring in automotive applications. So far, the dynamical behavior of gasoline reformers is poorly understood. Therefore, we are developing dynamic models of reformers to gain more knowledge about the dynamics of the system. These models will serve as virtual test benches for the development and evaluation of future control strategies.

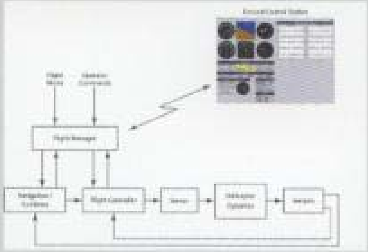
CNG Engines

Spark ignition engines powered by compressed natural gas (CNG) offer a wide range of advantages. Natural gas (NG) is available worldwide, it is not poisonous, its production might be regenerative, its carbon-to-hydrogen ratio is advantageous for the reduction of CO_2, and while there are lots of alternative products from crude oil besides gasoline, combustion is about the only use for natural gas.

In addition to these advantages, if in a stoichiometric combustion process CNG is used together with state-of-the-art catalytic converters, extremely low emissions standards are attained (down to equivalent zero emission). The high knock resistance of CNG is ideal for supercharging and thus for downsizing the engine, which results in another CO_2 reduction. Existing gasoline engine management systems can be adapted for use with CNG engines. Although a certain amount of parametrization work is necessary, there are no special hardware development efforts required.

All these advantages motivated the conception of the Clean Engine Vehicle (CEV) project as a joint project between the Measurement and Control Laboratory and the Aero-Chemistry Laboratory of ETH, the Swiss Federal Laboratory for Material Testing and Research (EMPA), and various industrial partners. A production-type Volkswagen Polo was modified for monovalent CNG operation. The loss of maximum power caused by the gaseous fuel injection was overcome with a turbocharger, which additionally serves to exploit the possibilities of supercharging the engine. Project goals are to lower the carbon dioxide

Kalman filters. For the design of model-based controllers nonlinear mathematical models of the aircraft have been developed. The problems of model identification, real-time programming, and path planning of autonomous air vehicles are being tackled as well. Indoor and outdoor flight experiments provide verification of the theoretical groundwork.

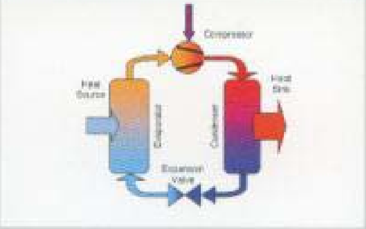


Unmanned aerial vehicle operating environment

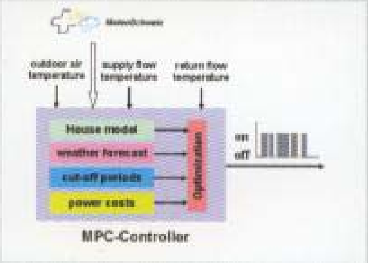
Ongoing research includes system modeling, integrated navigation, robust flight control (model-based controller), closed-loop model identification, data fusion, autonomous mission management, and stability augmentation for unmanned aerial vehicles.

Adaptive Model Predictive Control for Heatpump Heating Systems

The heatpump heating systems in single family houses typically are controlled with a relay-type controller for the return flow temperature. This type of controller permits sufficient comfort for the residents, but generally it is unable to take into account the dependence of the heatpump's efficiency on the outdoor air temperature. Therefore the heatpump consumes more electrical energy and thus keeps the heating costs higher than necessary.



The main goal of this research project is to determine the required heating energy with regard to the thermal behavior of the building, the weather forecast, the power costs (high and low tariff), and the power cut-off times demanded by electric power providers. In addition, since a heatpump can only be switched on or off, the required heating energy has to be quantified. This is achieved by means of pulse-width modulation with regard to the optimal performance of the heatpump.



The Model Predictive Control (MPC) design technique is chosen for the development of the complex controller required to take all those effects into account. As an added benefit, this control strategy also allows the warm-water supply to be controlled. Furthermore, we are developing in this project a self-adapting MPC-controller. Its function is to automatically detect the thermal behavior of the house and its heating system by on-line parameter identification techniques in order to adjust the controller parameters according to preset demands.

A dynamic test bench for brine-to-water heatpumps has been developed which allows the emulation of the thermal behavior of a virtual house as well as that of a fictitious earth probe. Thus the various control strategies may be tested and compared prior to their implementation.

Financial Control

Financial control deals with decision-making in real-world finance problems. Financial optimization problems are inherently dynamic control problems in complex stochastic systems, which makes them well suited for an optimal-control approach. Research is based on three core areas: financial modeling, stochastic optimal control, and real-world applications.

Financial modeling is applied to a variety of problem areas in finance. For instance, asset-liability models are developed for the optimization of pension funds and life insurance. Known portfolio models are extended to describe portfolios with complex financial products, as are asset price models that reflect the true statistical properties of the asset-price time series of existing asset prices. Risk modeling is undertaken in order to accurately capture the risk associated with different investment classes.

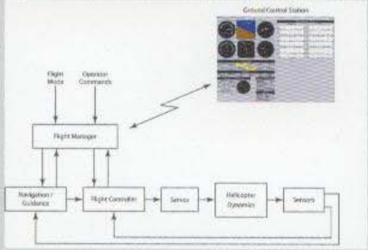
Stochastic control theory is used to derive optimal decision sets to optimize various real-world finance problems. Optimal decision rules have been derived either analytically or numerically for portfolio optimization problems or pension-fund asset-liability management. Filtering and estimation applied to parameter identification of financial models is another field of active research. Furthermore, properties of complex stochastic systems are investigated in order to describe fundamental characteristics of real financial applications, e.g., the attainability of certain portfolio levels.

A broad field of financial applications is investigated and promising methods are developed. For example, asset management solutions to improve risk-return characteristics for medium- to-short term investment horizons are developed. Pension-fund optimizations for long-term investment strategies with given liability structures represent another current research topic. Moreover, dynamical portfolio optimizations with alternative investments are under investigation.

Internet project «Measurement Science and Technology»

In a cooperative effort with Swiss Universities of Applied Sciences, metas, and others, we are developing an internet portal designed to provide users in academia, industry, and trade associations with the fundamentals of measurement science and techniques. In an attractive, user-friendly, yet challenging manner, this on-line learning unit is to provide users with an overview of the essentials. In-depth specifics, continuing education modules relating to diverse areas of expertise, as well as training materials and interactive experiments are some other alternatives available, with an emphasis on a consistent presentation of the contents. Another feature of this internet portal is the support of the production of various kinds of material for teaching.

Kalman filters. For the design of model-based controllers nonlinear mathematical models of the aircraft have been developed. The problems of model identification, real-time programming, and path planning of autonomous air vehicles are being tackled as well. Indoor and outdoor flight experiments provide verification of the theoretical groundwork.



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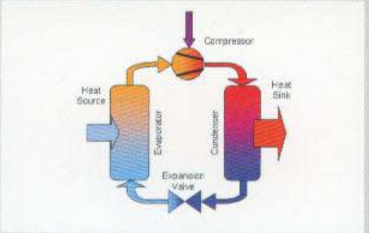

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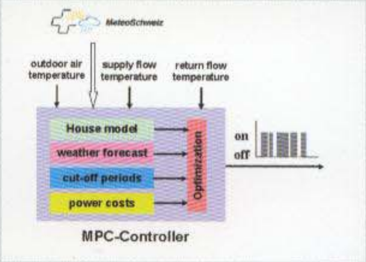

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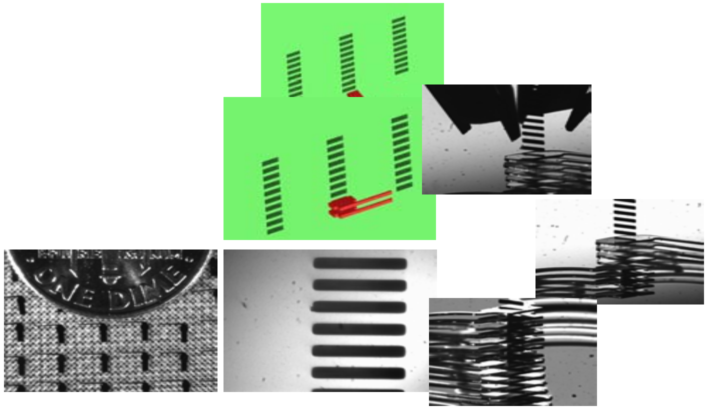
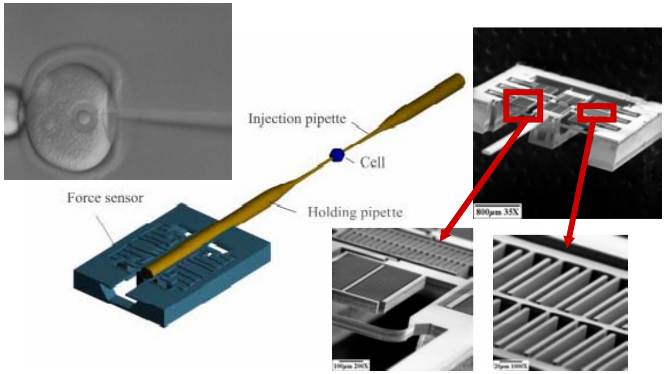
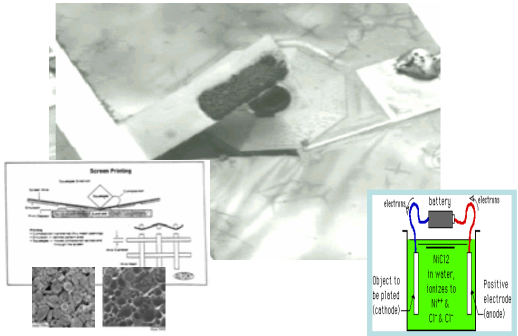
IRIS Research and Education Focus Areas in Mechatronics



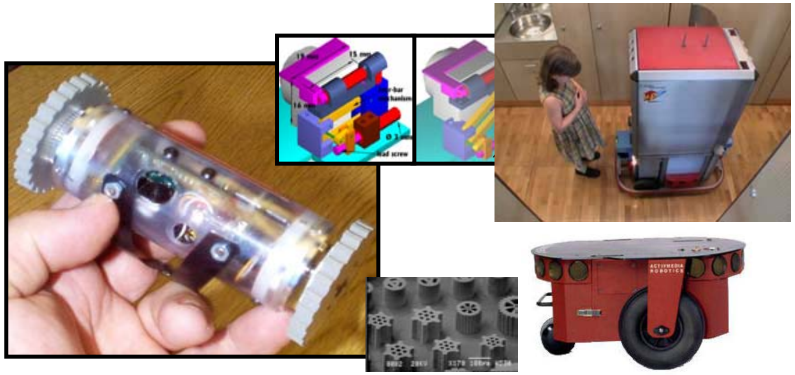
Wafer-level Microassembly



BioMicroRobotics



Magnetic Microactuators and Deposition of Hard Micromagnets

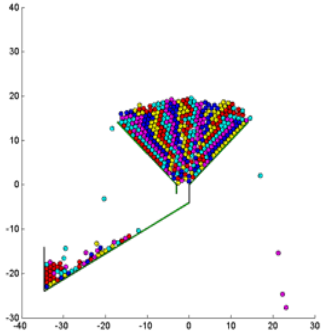


Distributed Mobile Robotics

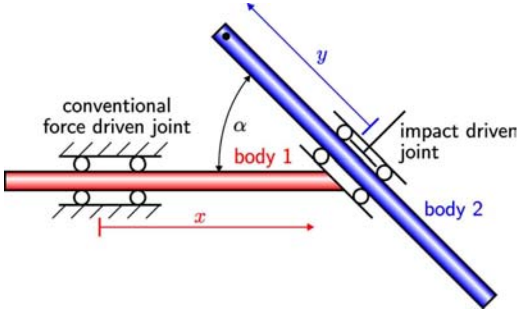
Center of Mechanics

Research in Non-Smooth Dynamics

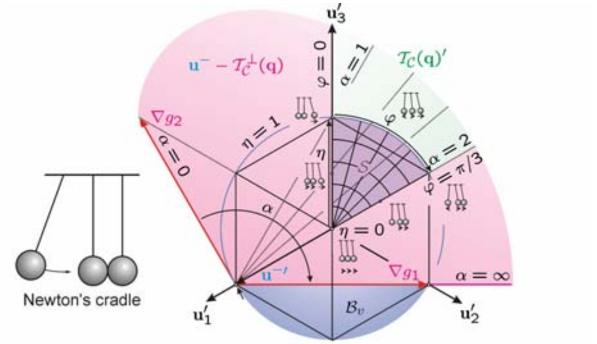
- ***Numerical Methods***



- ***Robotic Manipulators***

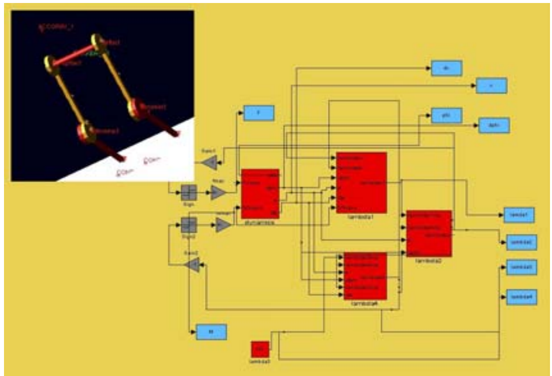


- ***Impact Theory***



$$\left.\begin{array}{lcl} u_1^+(\varphi,\eta) & = & \frac{v}{3}\big(1-\eta(\cos\varphi+\sqrt{3}\sin\varphi)\big) \\ u_2^+(\varphi,\eta) & = & \frac{v}{3}\big(1-\eta(\cos\varphi-\sqrt{3}\sin\varphi)\big) \\ u_3^+(\varphi,\eta) & = & \frac{v}{3}\big(1+2\eta\cos\varphi)\big) \end{array}\right\} \quad 0 \le \varphi \le \frac{\pi}{3}, \quad 0 \le \eta \le 1$$

- ***Control Strategies***

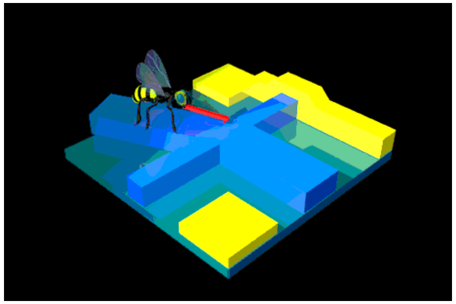


Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Center of Mechanics
Prof. Dr.-Ing. Ch. Glocker
ETH Zentrum
CH- 8092 Zürich

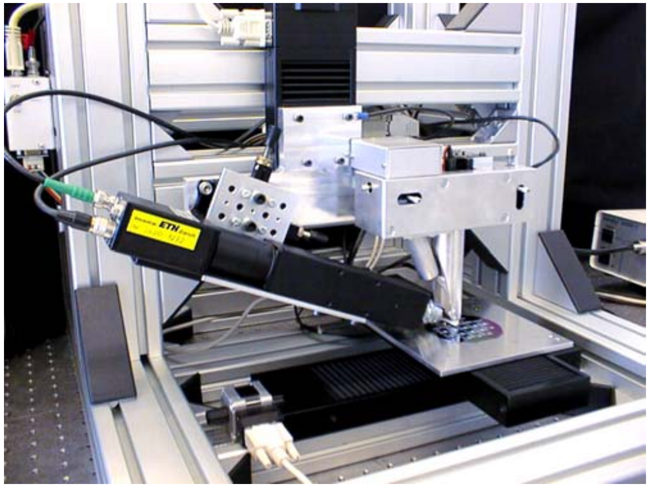
IMES
Institute of Mechanical Systems

Mechatronics Projects

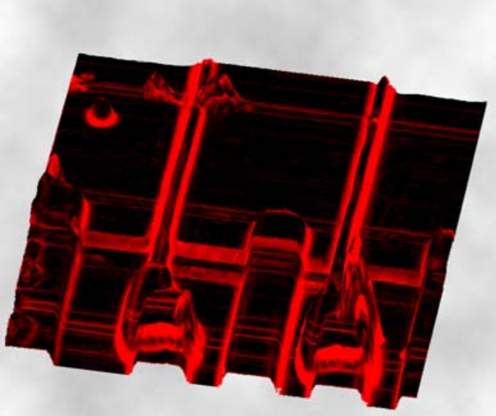


Sensor-guided nanorobot: the concept.

Polyproject NANO II
Sensor-guided nanorobot

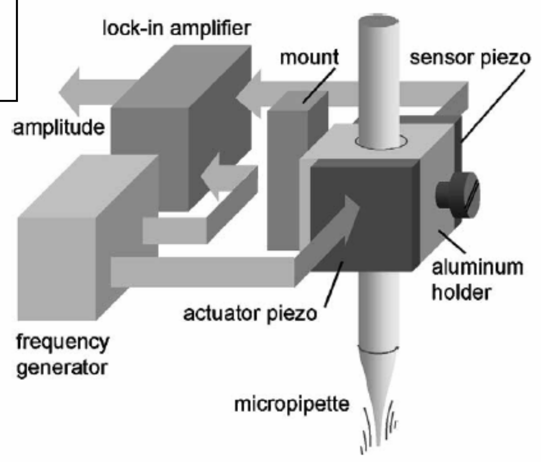


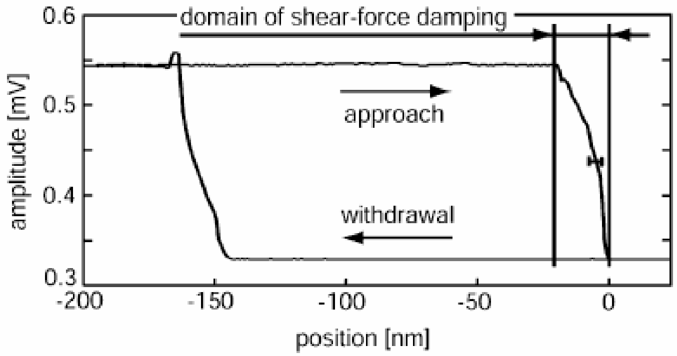
Sensor-guided nanorobot: automatically locates and analyses device structures on wafer.
Combines AFM, light microscopy and *a priori* knowledge of user.



HEMT: Surface topography with color-coded electric field strength.

Sensor Tools
Micropipette with integrated shear-force distance sensor

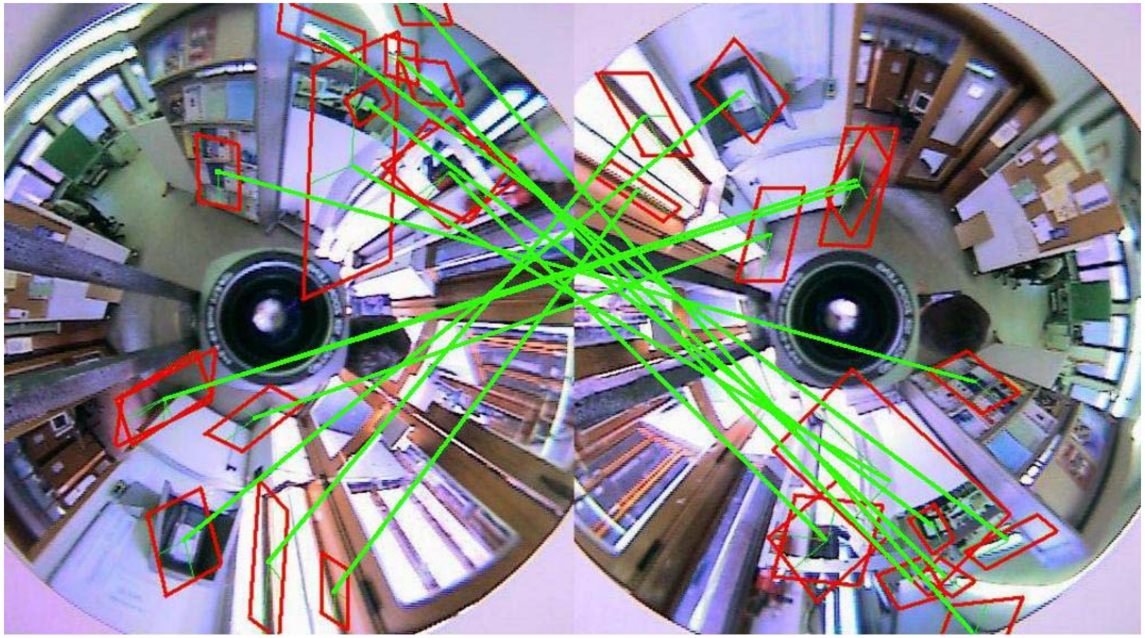




Goal: **visual localization** and **navigation** of **mobile robots**, i.c. wheelchairs for severely disabled people or wearable systems, without the use of special markers

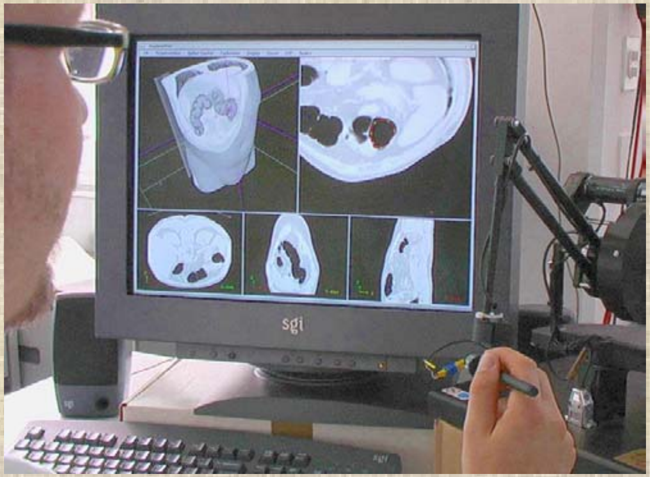
Method:

- Extraction of **local features** that are immune against changes in viewpoint and illumination, and that are natural parts of the scene.
- **Topological** rather than 3D environment **maps** are built, thereby reducing the cost of equipment (normal camera) and facilitating training, model building and path planning.



Computer Vision Laboratory
Medical image analysis and visualization

Virtual model of the uterine cavity with a polyp



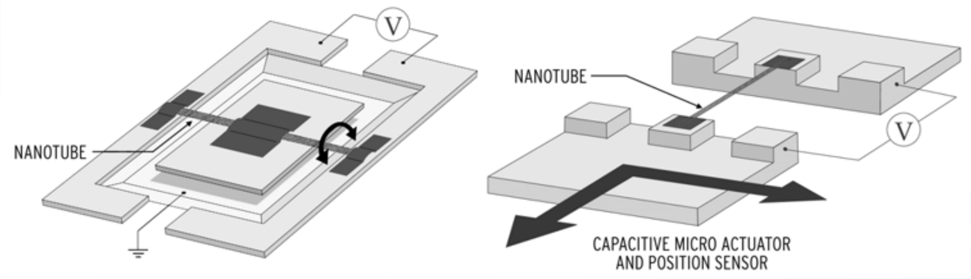
Visuo-haptic 3D data exploration system

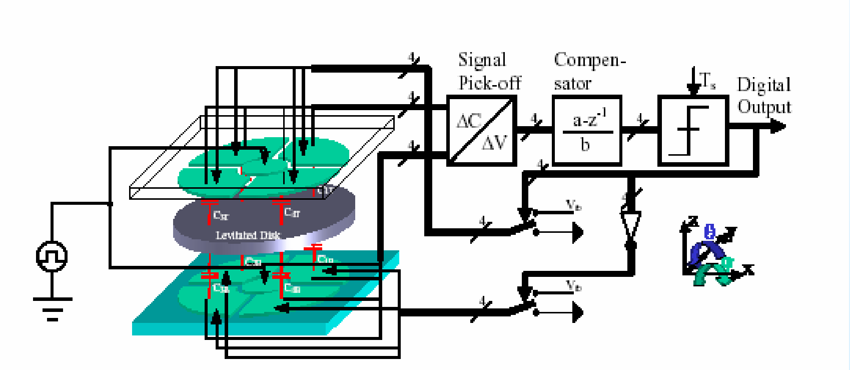
- Virtual and augmented reality technology for training
  - photorealistic visualization of surgical scenes
  - simulation of tissue behaviour
  - simulation of interactions with soft materials
  - graphical CFD methods for flow visualization
  - haptic interaction, force feedback
- Multi-modal immersive virtual reality environments for data exploration
  - computer haptics
  - combined visual and haptic feedback
  - interactive exploration of volumetric data

Micro and Nanosystems Chair – Focus

MICRO AND NANO SENSORS BASED ON:

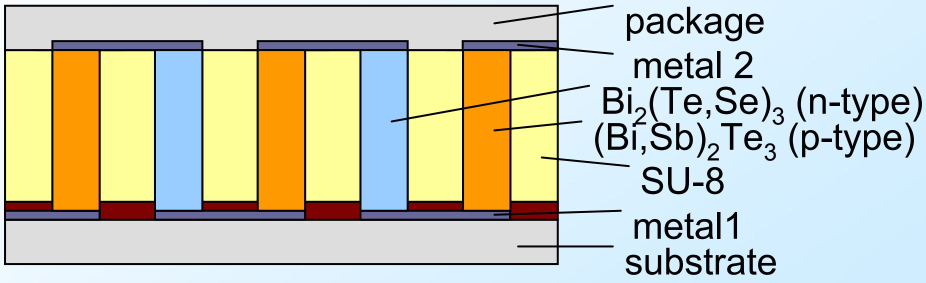
- Polymer and biocompatible MEMS materials
- Carbon nanotube electromechanical properties
- Micro scale electrostatic bearings





MICROSCALE POWER GENERATION:

- Thermoelectric microstructure arrays: Potential for electrical power from heat generated by human body



Micro and Nanosystems Chair – Focus

MICRO AND NANOSTRUCTURING:

- Polymer and polysilicon deposition and/or structuring
- Growth and integration of nanotubes with microsystems

TEST METHODOLOGY AND CHARACTERIZATION

- Evaluation of micro and nano electromechanical systems
- Biocompatible and other microstructured material property evaluation (viscoelastic effects, stress, aging, etc.)