Advanced Mechatronic System Design

Background of the workshop

Idea:
- Provide intensive training in mechatronic system design on a new and uncertain business case based on vague requirements (close to reality!)
- Interactive participation in workshop/masterclass environment.
- Related to the Dutch high-tech industry
- Provided by experienced system designers
- On top of the Mechatronics courses of Mechatronics Academy
- Covering a broad range of subjects
- With adaptable content, when required

Step 3: Electrical version of H-drive

3 DOF active controlled, 3 DOF passive guided, but.......

Vibration transmission and bearing issues prohibit its use in a scanner.

The aperture stop determines the diffraction limited resolution. It is an optical low-pass filter.
Contents

- Mechatronics Training Curriculum
- Details of Course Advanced Mechatronic System Design
Mechatronics Training Curriculum

Premium
- Advanced Motion Control
  - 5 days
- Advanced Feedforward & Learning Control
  - 3 days
- Passive Damping for High Tech Systems
  - 3 days
- Masterclass Design Principles
  - On request

Advanced
- Motion Control Tuning
  - 5 days
- Dynamics and Modelling
  - 3 days
- Design Principles for Precision Eng.
  - 5 days
- Basics and Design for Ultra Clean Vacuum
  - 4 days
- Experimental Techniques in Mechatronics
  - 3 days
- Metrology & Calibration of Mechatronic Systems
  - 3 days
- Actuation and Power Electronics
  - 3 days
- Machine Vision for Mechatronic Systems
  - 2 days
- Thermal Effects in Mechatronic Systems
  - 3 days

Standard
- Advanced Mechatronic System Design
  - 6 days
- Workshop Mechatronics System Design
  - On request

Basic
- Mechatronics System Design – part 2
  - 5 days
- Mechatronics System Design – part 1
  - 5 days

Relevant partner trainings:
- Applied Optics
- Electronics for non-electrical engineers
- System Architecture
- Soft skills for technology professionals
...

www.mechatronics-academy.nl
In the past, many trainings were developed within Philips to train own staff, but the training center CTT stopped.  

**Mechatronics Academy B.V.** has been setup to provide continuity of the existing trainings and develop new trainings in the field of precision mechatronics. It is founded and run by:

- Prof. Maarten Steinbuch
- Prof. Jan van Eijk
- Dr. Adrian Rankers

We cooperate in the **High Tech Institute** consortium that provides sales, marketing and back office functions.
Advanced Mechatronic System Design
Course Director(s) / Trainers

Teachers
- Prof.ir. Rob Munnig Schmidt (TUDelft / RMS Acoustics & Mechatronics)
- Ir. Ad Vermeer (AdInsyde)
- Dr.ir. Adrian Rankers (Mechatronics Academy)
- Ir. Hans v.d. Rijdt (van de Rijdt Innovatie)
- Rob Oldenburg (Sales Improvement Group)

Course Director(s)
- Prof.dr.ir. Jan van Eijk (MiceBV)
- Dr.ir A.M. Rankers (Mechatronics Academy)
<table>
<thead>
<tr>
<th>Day</th>
<th>Session</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Topic</th>
<th>Presenter</th>
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<tbody>
<tr>
<td>Day 1</td>
<td>Morning</td>
<td>09.00</td>
<td>09.30</td>
<td>Introduction (who-is-who, goals, expectations, ....)</td>
<td>Rob</td>
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<tr>
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<td>11.30</td>
<td></td>
<td>Introduction Case</td>
<td>Rob/Ad</td>
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<tr>
<td></td>
<td>Afternoon</td>
<td>13.30</td>
<td>15.30</td>
<td>Team Work (discussion of assignment, understanding, clarifying, ....)</td>
<td>Ad</td>
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<td>Optical Systems for Imaging (focus on case)</td>
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<td>System Decomposition Overview (SDO) incl. weekend assignment</td>
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<tr>
<td>Day 2</td>
<td>Morning</td>
<td>09.00</td>
<td>10.30</td>
<td>Team discussion (understanding/Questions URS, Initial Concept(s) + SDO</td>
<td>Ad</td>
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<td></td>
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<td>11.30</td>
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<td>Plenary discussion</td>
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<td>Agile Systems Engineering Principles</td>
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<td>incl. (agile) V-model, (agile) requirements, decomposition, ....</td>
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<td></td>
<td>Afternoon</td>
<td>13.30</td>
<td>15.00</td>
<td>Team Exercise Agile Systems Engineering incl. preparation of initial</td>
<td>Ad</td>
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<td>16.30</td>
<td>customer feedback presentation (draft of requirements, deliverables,</td>
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<td>....) to “test” whether you are in sync with the customer</td>
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<td>3 x (10min presentation+20min discussion on contents &amp; presentation)</td>
<td>Rob/Ad + Rob Oldenburg</td>
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<td>Is your audience yellow, blue, green or red ?</td>
<td>Rob Oldenburg</td>
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<tr>
<td>Day 3</td>
<td>Morning</td>
<td>09.00</td>
<td>10.00</td>
<td>Layout &amp; Motion Concepts</td>
<td>Ad</td>
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<td>Team Work</td>
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<td></td>
<td>Afternoon</td>
<td>13.30</td>
<td>15.00</td>
<td>Risk Assessment</td>
<td>Ad</td>
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<td>Team Work</td>
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<td>Evening*</td>
<td>18.00</td>
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<td>Dinner (Auberge Nassau)</td>
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<tr>
<td>Day 4</td>
<td>Morning</td>
<td>09.00</td>
<td>10.30</td>
<td>Design for (Service) Costs</td>
<td>Hans v.d. Rijdt</td>
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<td>Team Work</td>
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<td>Afternoon</td>
<td>13.30</td>
<td>15.30</td>
<td>Precision Drive &amp; Sensing Principles</td>
<td>Ad</td>
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<td>Team Work</td>
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<tr>
<td>Day 5</td>
<td>Morning</td>
<td>09.00</td>
<td>12.00</td>
<td>Vibrations &amp; Dyn. Error Budgetting</td>
<td>Adrian</td>
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<td>Decision Tables</td>
<td>Ad</td>
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<td>Afternoon</td>
<td>13.30</td>
<td>15.00</td>
<td>Conceptual Thermal Analysis (30% accuracy calculations)</td>
<td>Ad</td>
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<td>Team Work</td>
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<tr>
<td>Day 6</td>
<td>Morning</td>
<td>09.00</td>
<td>10.00</td>
<td>Example presentation of a real project</td>
<td>Rob</td>
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<td>Preparation Customer Meeting</td>
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<td></td>
<td>Afternoon</td>
<td>13.30</td>
<td>16.00</td>
<td>3x Customer Presentation (20min + 20min discussion)</td>
<td>Rob/ Ad / Guest</td>
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<td>Evaluation incl. most important lessons learned &amp; improvement points</td>
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</table>
Day 1 (morning): Introduction / Case

Background of the workshop

Idea:
- Provide intensive training in mechatronic system design on a new and uncertain business case based on vague requirements (close to reality!)
- Interactive participation in workshop/masterclass environment.
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- Provided by experienced system designers
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- Covering a broad range of subjects
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Top down approach

The participant will be confronted with aspects on different levels:
- The product creation process including creativity and innovation-targeted process steps based on vague “customer requirements”
- The fact that the customer is in fact multiple persons with often different views
- Technical trade-offs on system level by teams of which the members have a different technical background.
- Recent insights/developments on module/function level.

So what will be the task in this workshop?

- Concept design of a flexible LCD/OLED pattern definition system, focusing on the huge diversity in small, high resolution displays used in smartphones and related products by breaking with the trend for ever larger substrates, preferably on a single item basis.
- Starting with a thorough investigation of requirements and working according to a systematic design process.
Day 1 (afternoon): Optical Systems …

Main message

1. The wavelength and radiance of a source of light determine the ability of a lithographic exposure system to concentrate light on a small spot.
2. A wavefront is an artificial concept that is used in visualising optical properties.
3. Geometric optics is a straightforward way to construct an image by means of ray-tracing.
4. Telecentricity is applied in technical optics to avoid magnification errors.
5. Pixel-grid imaging differs from normal imaging in the way how a total image is created.

The aperture stop determines the diffraction limited resolution. It is an optical low-pass filter.

A narrow aperture stop in an afocal lens makes it telecentric

System Decomposition Overview

Pixel grid imaging is like working with a beamer

- Image is created by combining light dots in different intensity
- Controllable by a programmable MEMS device
- Driven from a digital source of information
- Flexible and fast

Advanced Mechatronic System Design – overview
Day 2 (morning):

Team Discussion
Agile Systems Engineering

Agile / Scrum

V-Model versus Evolutionary PCP Model

Scrum Board: Daily standup meeting
Day 2 (afternoon): Case + Presentation

Some Technical Presentation Tips and Tricks

Advanced Mechatronic System Design – overview
Day 3 (morning): Layout Concepts

Breakdown of motion system requirements and constraints

- Imaging:
  - Guarantee vibration free environment of exposure system
  - 6 DOF Position measurement of wafer relative to lens
- Overlay:
  - Same requirements as with imaging plus:
  - Position calibration of image to wafer (alignment)
- Throughput:
  - Avoid waiting times, keep lens always active imaging
  - Accurate positioning at high speed

1:1 projection Perkin-Elmer (SVG-ASML) Micralign (1973)

Disruptive, paradigm shifting technology of a waferstepper (Philips 1971)

- Smaller exposure area
- Alignment per die possible
- High NA only at imaging side
- Mask manufacturing less critical
- No contact

Step 3: Electrical version of H-drive

- 3 DOF active controlled, 3 DOF passive guided, but........
- Vibration transmission and bearing issues prohibit its use in a scanner.

Dynamic architecture Twinscan
Day 3 (afternoon): Risk Assessment

Identifying risks early in project

- Finding risks is a creative process
- Structured creativity by Fish Bone diagram
- Follow Ground Rules for Creativity:
  - Quantity above Quality
  - Cross Stimulation
  - Suspended Judgment
  - Writing it down
  - Listening
- Suggestion: Start with “brainwriting”

Example risk mitigation: HVT SoLayTec

Early risk confrontation by test rigs

Assignment (2): Use FMEA

- Start from System Decomposition Overview
- Follow FMEA workflow on concept level
- Use FMEA Template
- Fill in main risks found with fish bone diagram
- Define Mitigation Strategy
  - Analysis of critical performance aspects
  - Plan B for critical elements
  - Test rigs, fast prototyping in project plan
Day 4 (morning): Design for Service

Content
- Philips Digital Pathology
- Some explanation on UFS
- Stage
- Optics
- Glass handling
- Service strategy
  - Assignment 1
  - Assignment 2

Alternative 1
Module exchange at customer, repair at supplier

- Customer Spare parts
- Customer Product
- OEM
- System Supplier
- Supplier component

Module (4,000 Euro)
Module (4,000 Euro)
Module (4,000 Euro)
Component (50 Euro)
Component (50 Euro)
Component (50 Euro)
Component (50 Euro)
Component (50 Euro)
Waste
New

Alternative 2
Module repair / component exchange at customer

- Customer Spare parts
- Customer Product
- OEM
- System Supplier
- Supplier component

Component exchange

Component (50 Euro)
Component (50 Euro)
Component (50 Euro)
Component (50 Euro)
Component (50 Euro)
Waste
New
Day 4 (afternoon): Precision Drives ...

Main message

1. The choice of the driving actuator depends on the disturbance sources in the application.
2. Actuators convert control action into real action. The amplifier is an inseparable part of the actuator.
3. Sensors convert physical “signals” into electrical signals. Electronics are key in this process.
4. Actuators in an active controlled motion system are characterised by one or more “nested” internal feedback loops with their impact on system dynamics and motion feedback stability.

Actuator possibilities

Different drive principles exist:
- Piezoelectric
- Electromagnetic
  - Lorentz
  - Variable reluctance
  - Hybrid (biased reluctance)
- Pneumatic
- Electrostatic

Distance to a conductive, parallel moving object

Process disturbances work on different elements in the plant

1. Amplifier noise
2. Process forces like from shisel (cutting tool)
3. Vibration transmissibility
Day 5 (morning): Vibrations & Dyn. Error

Pushing the limits ...

1. Optimize Dynamics for Control
2. Bandwidth > 200Hz
3. Sensitivity < 50pm/2.5mN
4. Tackle Over-specification

Reduce Disturbances

Disturbance: 2.5 mN

Requirement: 50 pm

CPS of $x_p$ with Initial Controller

Sensor Noise

- VTP sensor
  - 100nm = 8σ ⇒ σ = 17nm white noise
- ADC – Quantization
  - uniformly distributed zero mean white noise frequency with \( \sigma^2 = \frac{15}{12} \)
  - 16bit = 1mm range ⇒ \( \sigma = \frac{1}{2} \cdot 1\text{mm} \cdot \sigma^2 = \frac{1}{2} \cdot 1\text{mm} \cdot \frac{15}{12} = \frac{15}{24} \text{nm} \)
- ADC – SNR
  - \( \text{SNR} = \text{RMS sinus full range / RMS noise} \)
  - \( \text{SNR} = 80\text{dB} \Rightarrow \sigma = \frac{1}{2} \cdot \frac{15}{24} / 10^4 \text{nm} \)
- Uncorrelated sources
  - \( \sigma_{\text{overall}} = \sqrt{\sum \sigma_i^2} \) = 39nm
  - \( \sigma_{\text{PSD overall}} = \sigma_{\text{overall}} / f_{\text{nyquist}} = 1.55 \text{nm/Hz} \)

Cumulative Power Spectrum (CPS)

\[ \text{PSD} = H_1^2 \cdot \text{PSD}_{w1} + H_2^2 \cdot \text{PSD}_{w2} + H_3^2 \cdot \text{PSD}_{w3} \]

RMS Floor Acceleration VC-C

Machine acceleration levels with/without vibration isolation system at VC-C (RMS 12.5 μm/s)
Day 5 (afternoon): Thermal Analysis

DSPE Website on Thermomechanics

Chapter 1: Basics of Thermomechanics
1.1 Temperature, heat and heat capacity
1.2 Heat transfer
1.3 Principles of thermal deformations
1.4 Thermo-mechanical beam equations (‘vergeet-mij-nietjes’)

Chapter 2: In Depth
2.1 Conduction in solids
2.2 Conduction in gasses
2.3 Thermal convection
2.4 Thermal radiation

Chapter 3: Thermomechanical design
3.1 Material selection
3.2 Geometry
3.3 Design principles
3.4 Passive thermal conditioning
3.5 Active thermal conditioning
3.6 Compensation
3.7 Summary

Chapter 4: Thermomechanical Modeling
4.1 Important variables
4.2 Lumped capacitance modeling
4.3 Advanced hand calculations
4.4 Numerical modeling

Chapter 5: Sensors
5.1 Contactless temperature sensors
5.2 Contact temperature sensors
5.3 Heat flux sensors

Chapter 6: Measurement
6.1 Calibration
6.2 Practical information

Chapter 7: Examples

Chapter 8: Miscellaneous

Summary heat transfer (DSPE website)

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<tbody>
<tr>
<td>Conduction</td>
<td>TC = (A / L)</td>
<td></td>
<td>Unidirectional conduction (over length L cross-section A)</td>
</tr>
<tr>
<td>Convection</td>
<td>TC = A / L</td>
<td></td>
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<tr>
<td>Radiation</td>
<td>TC = ( 1 - \frac{\rho L}{\kappa} \cdot (1 - \frac{1}{R}) )</td>
<td>Typical value for laminar water flow: ( \kappa = 1000 [W/mK] )</td>
<td></td>
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<tr>
<td>Contacting surfaces</td>
<td>* Dry contact: TC = A ( \rho L / d )</td>
<td>Gap material: TC = A ( \rho L / d )</td>
<td>Typical value for dry contact at moderate pressure: ( \kappa = 100 - 1000 [W/mK] )</td>
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</tbody>
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Heat transfer through blocks due to convection outside

Uniform and non-uniform expansion

Aluminium: \( \lambda = 210 [W/mK] \)

Thickness each (top and bottom) plate \( d = 0.04 [m] \)

Area top/bottom side \( A = 0.2 \times 0.2 = 0.04 [m^2] \)

Heat flux natural convection \( q = 5 [W/mK] \cdot \delta T \cdot A = 5 \times 0.04 = 0.20 [W] \)

Temperature difference between top and bottom of both plates in steady state:

\[ \Delta T = \frac{(\rho \cdot d)}{A \cdot \lambda} = \frac{40 \times 0.04}{0.04 \times 210} = 0.19 [K] \]
Day 6 (morning): Real Life Example

Flexible Small Flat Panel Display manufacturing
a case study

Rob Munnig Schmidt
Day 6 (afternoon): Customer Presentation

Customer Presentation of each team
- Technical concept(s)
- Plan how to proceed
- Convincing the customer

Evaluations / Lessons Learned
Sign-up for this training

Via the website of our partner
High Tech Institute