PROGRAMME

60th ISC

Ilmenau Scientific Colloquium
Technische Universität Ilmenau

September 4 – 8, 2023

»Engineering for a Changing World«

Department of
Mechanical Engineering

TECHNISCHE UNIVERSITÄT
ILMENAU

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Dear Conference Participants!

After two years of postponement due to the pandemic, we are very pleased to welcome you in person to Technische Universität Ilmenau for the 60th Ilmenau Scientific Colloquium. As the first ISC was held in 1956, this colloquium is one of the longest continuing scientific conferences in bridging disciplines of and around Mechanical Engineering.
In 2023, the Ilmenau Scientific Colloquium is once more organised by the Department of Mechanical Engineering. The title of this year's conference

"Engineering for a Changing World"

refers to limited natural resources of our planet, to massive changes in cooperation between continents, countries, institutions and people – enabled by the increased implementation of information technology as the probably most dominant driver in many fields. The Colloquium, supplemented by workshops, is characterised but not limited to the following topics:

- Precision engineering and measurement technology Nanofabrication
- Industry 4.0 and digitalisation in mechanical engineering
- Mechatronics, biomechatronics and mechanism technology
- Systems engineering
- Productive teaming - Human-machine collaboration in the production environment

The topics are oriented on key strategic aspects of research and teaching in Mechanical Engineering at our university. As always in the long series of ISC conferences, we have invited and encouraged contributions from both academia and industry. We are very much pleased about the overwhelming response. The international high-profile scientific committee selected more than 160 contributions from 14 different countries for the presentation. The range of subjects certainly reflects the interdisciplinary nature of the conference topics and will fruitfully bring together experts from industry and academia. We are confident that the ISC will be the perfect platform for discussion, establishing new contacts and for the beginning or continuation of cooperative projects. No matter whether you are an experienced professional or a novice in mechanical engineering – we are convinced that the 60th Ilmenau Scientific Colloquium will be of benefit to you.
Besides an enriching and interesting conference, we wish you an enjoyable stay in the town of Ilmenau and its surroundings that was already highly appreciated by Johann Wolfgang Goethe who said:
"Ilmenau has cost me a lot of time, effort and money; but in return I have learned something and acquired a view of nature that I would not want to exchange at any price."
May this conference leave you in a similarly enriched state.

Professor Kai-Uwe Sattler
President of the
Technische Universität Ilmenau

Professor René Theska
Head of Organization

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CONFERENCE PROGRAMME AT A GLANCE - 60th Ilmenau Scientific Colloquium (ISC) | September 4 – 8, 2023

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Monday, 4.09.23 10:00 a.m. – 12:00 noon 12:00 noon – 12:45 p.m.	Audimax | **Opening ceremony and plenary lectures** (Prof. Dr. Heike Riel | Dr. Andreas Kaufer) **Silicon science award** HU-131 | Press meeting									Conference office | Installation companies
1.30 p.m. - 4.30 p.m.								**1.1**		
5:00 p.m. – 7:00 p.m.	Foyer and outside of Humboldt building | Welcome reception for all speakers, participants and guests									
Tuesday, 5.09.23 9:00 a.m. - 10:00 a.m.	HU-HS | Plenary lecture (Prof. Dr. Cornelia Denz)									
10:40 am. – 12:00 noon	**3.3**		**4.1**	**4.2 +** Poster Pitches	**3.2**	**3.1**	**2.1**	**1.1**		
12:00 noon - 1:30 p.m.	**Foyer Humboldt building | Poster session**									
1:30 p.m. – 4:30 p.m.	**3.3**	**1.4**	**2.2 +** Poster pitches	**4.2**	**3.2**	**3.1 +** Poster Pitch	**2.1 +** Poster Pitches	**1.3**		Conference office | Visits of expositions
Wednesday, 6.09.23 9:00 a.m. - 12:00 noon		**1.4**	**4.3**	**4.2**		**WS 1**	**1.2**	**2.3**		
1:00 p.m. - 3:00 p.m.		**1.4 +** Poster Pitches			Poster-Pitches **1.1, 1.3**					
3:15 p.m. – 10:30 p.m.	Excursion to Erfurt - Sightseeing tour Erfurt | organ concert | conference dinner									
Thursday, 7.09.23 9:00 a.m. - 12:00 noon						**WS 1**		**5.3, 5.4 +** Poster-Pitches **5.1,5.2, 5.3, 5.4**		
12:00 noon - 1:30 p.m.	**Foyer Humboldt building | Poster session**									
1:30 p.m. - 4:30 p.m.								**5.1, 5.2**		
Friday, 8.09.23 9:00 a.m. - 12:00 noon								**WS 2**		
Legend	Sessions of the 60th ISC					Social events of the 60th ISC			Workshops	

Workshop WS1 – Living glass surfaces XII
Workshop WS2 – Mechanical and precision engineering - methods, tools and applications for the 21st century

Registration | Conference office

Organisation

Technische Universität Ilmenau
Conference Management | Conference office
Mrs Andrea Schneider | Mrs Valeria Wahl

Conference 0ffice/ Conference building

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Opening hours/ Registration

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TU Ilmenau, Gustav-Kirchhoff-Platz 1
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Monday, 04.09.23	8:00 p.m. – 8:00 p.m.
Tuesday, 05.09.23	8:00 a.m. – 5:30 p.m.
Wednesday, 06.09.23	8:00 a.m. – 3:00 p.m.
Thursday, 07.09.23	8:00 a.m. – 5:30 p.m.
Friday, 08.09.23	8:00 a.m. – 1:30 p.m.

General information

Catering | Wi-Fi-Access | Parking

Coffee break

At the colloquium, refreshments will be offered during the coffee breaks in the foyer of the conference building.

Meals and refreshments

All participants may take advantage of the catering service in the Mensa (refectory) of the university. You can get there within a few walking minutes from the conference building.

Wi-Fi-Access

Wi-Fi is available throughout the 60th ISC in all lecture halls and lecture rooms.

SSID: TUI-Guest

You will be redirected to
https://beaker.net.tu-ilmenau.de/login.html

Login: **60ISC2023** Password: **confpart**

Free parking

On the campus, the signposting system will help you find the way to the conference building (Humboldt building) easily.

We have reserved for you the parking space right behind the building "Arrhenius" near the conference building. From there, you can reach the Conference building – (Humboldt building) on foot within a few minutes.

Conference programme

Opening | Plenary | Silicon science award

Monday, 04.09.23 10:00 a.m. – 12:00 noon/ Audimax	Musical opening on the piano Pianist | Ramon Heil-Sauerbrey
Moderation	Professor René Theska Head of organisation of the 60th ISC
10:05 a.m.	**Welcoming speeches by** - Professor Stefan Sinzinger Vice President for Research and Young Scientists - State Secretary, Carsten Feller Representative of TMWWDG - Professor Jean-Pierre Bergmann Dean, Department of Mechanical Engineering
10:15 a.m.	**Plenary lectures** Professor Heike Riel | IBM Fellow, Head of Science & Technology and Lead of IBM Research Quantum Europe at IBM Research, Zurich **"Nanoscience & Nanotechnology – Powering the digitalization of our world"** Dr. Andreas Kaufer | Director La Silla Paranal Observatory, Santiano, Chile **"European Southern Observatory – from precision engineering to precision astronomy"**
11:30 a.m.	**Silicon science award** Laudation and honours of the award winners
11:55 a.m.	Musical closing
12:00 noon	End of opening ceremony and plenary

Conference programme

Plenary

Tuesday, 05.09.23
9.00 -10:00 a.m.
Humboldt Lecture-Hall

Plenary lecture
Professor Cornelia Denz | President Physikalisch-Technische Bundesanstalt Braunschweig

Topic 1

Precision engineering and measurement technology

Session 1.1 Precision measurement technology

Time: Monday, 04.09.2023
Location: Humboldtbau, Lecture Hall (HU-HS)
Chairman: E. Manske (D-Ilmenau)

1:30 p.m.	**Invited lecture** T. Dziomba, A. Felgner, S. Gao (D-Braunschweig), M. Hemmleb (D-Halle), M. Ritter (D-Hamburg), E. Gärtner, J. Frühauf (D-Limbach-Oberfrohna)

How reliable are optical measurements of surface roughness?

Roughness is often decisive for the function of a workpiece. Consequently, the correct measurement of roughness according to generally accepted rules (standards such as the ISO 25178 series, and guidelines) is essential to achieve comparability in measurement and thus interchangeability of parts in production. While classical stylus profilometry is widely used already for many decades with well-established rules for roughness measurement & analysis (most recently revised in the new ISO 21920 series), areal roughness measurements by optical methods are increasing applied as fast and non-destructive techniques. However, many – often hidden – artefacts limit their practical use. Their performance in topography measurements strongly depends on the measurement/analysis principle and the set-up components (like objectives), which have effects not only on the spatial resolution, but also e.g. on the slope/curvature measurement capabilities. Systematic investigations on topography fidelity were therefore performed on both various types of roughness samples as well as reference samples optimized for instrument characterization. Different optical measurement techniques were analysed, usually with Atomic Force Microscopy (AFM) as reference method, to reveal some of the typical, critical artefacts specific to Confocal Laser Scanning Microscopy (CLSM) or White-Light Interference Microcopy (WLI), with the aim of helping users find a suitable measurement technique.

2:00 p.m.	Xin Xu, T. Pahl, H. Serbes, P. Lehmann (D-Kassel)

Robust algorithm for profilometry of very rough surfaces by applying focus variation microscopy

Focus variation microscopy (FVM) is an optical method that reconstructs rough surfaces by detecting the foci with respect to the pixels of a CCD/CMOS camera. The detection is based on the intensity contrast of local regions centered by each single pixel. Therefore, it requires the surfaces observed to have a certain degree of roughness. The individual focus of each pixel is obtained at different depth levels in an image stack. As a result, focus detection gives information on the corresponding depth level, and the surface topography can be reconstructed.

When using such an optical profiler to measure rough surfaces, especially surfaces generated by metal additive manufacturing, topographical artifacts such as spikes on a reconstructed surface are nearly unavoidable. These may affect the determination of roughness parameters of the topography and lead to erroneous surface features. This paper proposes a new preprocessing method to eliminate most artifacts before extracting surface heights of rough surfaces measured by focus variation microscopy. In this method, the axial region where a surface height value is located with the highest probability is estimated, based on datasets of planes parallel to the axial scanning direction. Results regarding height measurements with and without the proposed method are compared by measuring a Rubert Microsurf 329 comparator test panel for reference and a workpiece produced by metal additive manufacturing.

2:20 p.m.	J. Belkner, J. Stauffenberg, J. Döll, C. Koppka, M. Breiter, I. Ortlepp, U. Gerhardt, E. Manske (D-Ilmenau)

High frequent, low noise and robust differential confocal microscopy on a Nano-Positioning Machine

2:40 p.m.	P. Köchert, C. Weichert, J. Flügge (D-Braunschweig)

Online Heydemann correction of displacement measuring interferometers

Displacement measuring interferometer systems are the instruments of choice for traceable and accurate measurements over length scales of nanometers to meters. The essence of this method is to determine the relative phase changes of superposed optical waves as a target reflector is moved, and to infer the reflector displacement with respect to the wavelength of the incorporated laser. Systematic errors have a considerable impact on the accuracy of Michelson-type interferometers. One of these systematic errors are periodic nonlinearities, which can result from the optical crosstalk between the measurement and reference arm. They can be avoided a priori by applying a design with spatially separated beam paths or can be minimized ex post by applying a correction to the ellipsoidal Lissajous figures. An online correction of periodic errors is beneficial in motion control applications where commercial interferometers are used within feedback loops to achieve a positioning in the sub-nanometer range. But these online methods suffer either from not compensating the quadrature phase shift or the signal processing has to be split onto various hardware architectures to solve a linear system of equations to process all those parameters.
We propose a signal processing method carried out on a single FPGA unit to compensate interferometer nonlinearities in real-time. First measurements with a heterodyne interferometer revealed that nonlinearities can be reduced from 1 nm to 0.07 nm.

3:00 – 3:20 p.m. Coffee break and Visits of Expositions	
3:20 p.m.	C. Möller, T. Klein, T. Ortlepp (D-Erfurt), I. Ortlepp, E. Manske (D-Ilmenau)

Transparent photodiodes for standing wave interferometer

3:40 p.m.	V. Shmagun, U. Gerhardt, E. Manske, T. Fröhlich, T. Kissinger (D-Ilmenau)

Resolution enhancement in Fabry-Perot interferometers through evaluation of multiple reflection using range-resolved interferometry

This work presents a novel approach for improving interferometer resolution with a relatively simple setup by combining the use of range-resolved interferometry and a high-finesse Fabry-Perot setup utilizing multiple reflections in the cavity to gradually increase the resolution. This approach could enable the measurement of small displacements with a potentially much higher resolution than current interferometry methods. A simple proof-of concept setup demonstrated the evaluation of up to four Fabry-Perot passes, while theoretically much higher sensitivity improvement factors should be possible.

4:00 p.m.	M. Meier, C. Weichert, J. Flügge (D-Braunschweig)

Comparison of fully fiber-coupled interferometer systems under vacuum Conditions

The PTB built a comparator setup for testing length measuring systems under vacuum conditions. The setup is equipped with a linear stage, closed loop controlled on the feedback of a 1.5D encoder over a movement range of 150 mm. The main measurement system is a heterodyne interferometer which achieves periodic nonlinearities of amplitudes below 10 pm. The comparator setup was characterized with a mirror positioned on the stage, reflecting the measurement as well as the reference beams. By this means, the influence of guiding errors on position-dependent measurement deviations of the fully fiber coupled setup was observed to be below 1.5 nm or 0.2 nm depending on the used fibers.

Three different commercially fiber interferometer systems were analyzed under vacuum conditions with the comparator setup. All tested systems are working with light sources in the 1550 nm wavelength band but differ in the amplitude of their periodic nonlinearities in the range between 10 pm and 28 nm. The tests of their resolution and stability were limited by vibrations in the comparator setup and the lack of adequate synchronization of the commercial systems. The ongoing investigations on the traceability of the systems under test can be performed based on the iodine stabilized laser of comparator interferometer.

4:20 p.m.	S. J. Fischer Calderon, G. Straube, T. Kissinger (D-Ilmenau)

A novel point-to-point length measurement concept based on range-resolved interferometry

In many fields of research and high-value industry, the estimation of distances and displacements is crucial. Due to their extremely high spatial resolution and flexible application possibilities interferometers are cross-sectorally used in measurement practice. However, classical length measuring interferometers are subject to two residual restrictions. On the one hand, only displacements that are exactly aligned to the interferometer optical axis can be measured. On the other hand, deviating refractive indices in the measuring and reference arm due to different atmospheric conditions represent an accuracy-limiting disturbance. In this paper, a new interferometric concept for length measurement is presented. The concept is based on the range-resolved interferometry technology which enables the simultaneous readout and evaluation of two symmetrical interferometric signals which result from the superposition of two non-collimated spherical wavefronts. This allows a point-to-point measurement between two optical fiber ends and the separation of undesired changes of the optical path length outside the measurement cavity and within the measurement cavity.

End of Session

Session 1.1 Precision measurement technology Time:
Tuesday, 05.09.2023
Location: Humboldt building, Lecture hall (HU-HS)
Chairman: T. Kissinger (D-Ilmenau)

10:20 - 10:40 a.m. Coffee break and Visits of Expositions	
10:40 a.m.	**Invited lecture** E. Manske (D-Ilmenau)
Nanopositioning and nanomeasuring technology at it's limits	
11:10 a.m.	R. Köning, E. Schöttka, J. Krüger, M. Janik, M. Schumann, B. Bodermann (D-Braunschweig)

Development of a test setup for the characterization of an optical microscope for high precision length metrology applications

We developed a test setup to qualify the performance of optical microscopes for dimensional metrology applications. It has been optimized using FEM calculations to exhibit a minimal susceptibility of the currently integrated high-performance UV microscope to thermal and mechanical influences of the ambient environment. In addition, we discussed the influence the main components, like the light source or the camera, on the performance of the microscope and provided related data. We also explained the alignment procedure. Furthermore, we developed a hardware and software concept that allows to acquire the image and position data as synchronously as possible, is flexible enough to integrate different cameras, and allows to experiment with different data acquisition schemes. The short-term repeatability (1?) of the line position and -width measurement obtained with the integrated UV microscope are 1 nm and 0.2 nm respectively. In long term measurements the maximum lateral and focus drift rate observed were 30- and 20 nm / hour respectively. The measured point spread function contained only radial symmetric optical aberrations. Using the Zernike-Nijboer theory, including only the defocus and spherical aberrations, fit residuals were obtained that contain systematic deviations in the order of the noise level.

11:30 a.m.	Chen-Yu Liao, His-Hui Lin, Liang-Chia Chen (TW-Taipei)

Development of a fiber laser interferometer for precise displacement measurement using wavelength modulation interferometry

A compact fiber laser interferometer was developed for precise displacement measurement using a 1550 nm DFB laser for wavelength modulation to 300 kHz. The interferometer includes a fiber laser, a fiber-optic interferometer, and a wavelength modulation system. The proposed technique provides nanometer resolution and utilizes a hydrogen cyanide (HCN) gas cell to monitor the laser's center

wavelength. A modulation depth compensation method was developed to ensure consistent modulation depth over a wide measurement range. Preliminary tests show that the total measurement deviation with a commercial interferometer is less than 40 nm over a 300 mm range with a measurement speed of 100 mm/s. This technology is useful for high-precision measurements in hostile environments.

11:50 a.m.	I. Hamann, J. Sanjuan, L. Kumanchik, C. Braxmeier (D-Ulm), M. Gohlke (D-Bremen), G. Wanner (D-Hannover)

A laser dilatometer setup to characterize dimensionally stable materials from 100 K to 300 K

In our structural dimensional metrology laboratory, we implemented a setup to determine coefficients of thermal expansions (CTE) of ultra-stable materials at temperatures from 300 K down to 100 K. Such low CTE materials are important for dimensionally stable structures in space and terrestrial applications, e. g. to enable precise measurements. This CTE characterization is done in the 10 ppb/K range by applying small temperature variation around dedicated absolute temperatures . In order to accommodate arbitrary sample materials, we bounce light off mirrors attached to the sample by custom mounts. The light and therefore the thermal-induced length variations is then analyzed by an interferometer with subnanometer sensitivity. Here, we present a more detailed investigation of a process during sample measurements using differential wavefront sensing (DWS).

Elevator pitches Session 1.1 Precision measurement technology | 1.3 Measurement and sensor technology

Time: Wednesday, 06.09.2023
Location: Humboldt building, Lecture room 204
Chairman: T. Fröhlich (D-Ilmenau)

1:00 p.m.	S. Yatsyshyn, M. Mykyjchuk, T. Bubela (UA-Lviv)

Development of quantum temperature standard and verification of thermoelectricity laws

Issues in nowadays Thermoelectricity is developing in 2 main areas:
• Thermoelectric phenomena and means for energy production. The main thing here is high parameters: thermoelectric quality factor ZT and similar coefficients;
• Thermoelectric phenomena and means for measuring temperature (thermoelectric thermometry). Here the main item seems to be the high stability of thermoelectric characteristics, or rather their temperature dependence. There exist reasons to update scientific and technological approaches to the considered thermoelectricity. These two areas are based on thermoelectricity laws which were revealed about 2 centuries ago and not verified yet, although the accuracy of measuring the temperature necessary for specifying thermoelectric constants and laws, in general, has significantly increased over the past few centuries

1:05 p.m.	J. Wagner, C. Niedermeier, A. Wagner (D-Regensburg)

Study of the effect of matting agents on the measureability of geometrical Objects

Optical metrology has witnessed remarkable advancements over the past few years and increased its applications in many different fields. This study focuses on the effects while using a form of matting to reduce reflective effects to improve the measurements. However, challenges such as surface reflections and illumination issues must be addressed to ensure error-free measurements. Both the effectiveness of these surface treatments and the associated deviation of the values get investigated. In addition, data from three measurement devices are used to obtain the required values with state-of-the-art accuracy. The experimental analysis of the effectiveness of the different matting methods takes at least 13 distinct methods and products into account. The layer thickness and the benefit of the matting get investigated to estimate the application options and limits. In addition, a brief guide is given for users of such matting, indicating the circumstances and criteria to be considered, such as the working environment and processing instructions. Finally, a recommendation is given to facilitate the selection of the type of matting after careful consideration.

1:10 p.m.	S. Yatsyshyn, X. Zeng (UA-Lviv)

Metrological Risks at design stage for multidisciplinary-based objects

A general course for evaluation of measuring uncertainty [1] regarding decision-making in conformity assessment is continuously developed since the topics become complex and multidisciplinary. Attention is focused on the statistical analysis of data recorded by the measurement system. In such a way conclude the acceptability of the applied measurement system through the quantitative expression of its indicators [2]. Such a task has to be solved considering not only the design stage but also the exploitation peculiarities.

1:15 p.m.	J. Thiesler, G. Dai, J. Degenhardt, R. Tutsch (D-Braunschweig)

Recent progress and challenges in AFM-based true-3D micro- and nanometrology

In this paper, challenges of true-3D nanometrology are discussed on four fundamental aspects: probing sensor, measurement strategy, tip geometry and structure/tip deformation. Our research progress addressing these challenges is introduced.

1:20 p.m.	T. Bubela, V. Yatsuk, S. Yatsyshyn (UA-Lviv)

Simulation of electrochemical systems by analyzing impedance spectra

Impedance spectra of low- and high-impedance non-electrical nature objects were investigated in different frequency ranges. For low-impedance objects circuits containing the capacity of the double electric layer and circuits with a constant phase element were synthesized. Data analysis showed that at frequencies higher than 1000 Hz, the substitution scheme, the capacity of the double electric layer, is not suitable for reproducing the properties of electrolyte solution because big errors. It is proved that the resistance simulation of the impedance of the electrolyte solution is valid for highly concentrated solutions in a wide range of frequencies. Only at frequencies exceeding (1÷5) MHz, it is necessary to introduce additional elements considering the relaxation in the electrolyte. There were studied the diffusion phenomena in the electrode. Comparison of the dependences of reproduction errors of substitution scheme elements containing a constant phase element and a Warburg element is available at frequencies range 50–1000 Hz. The equivalent circuit of a low-impedance object can be represented by a constant phase element and the Warburg impedance that adequately describes the system at high frequencies (1–100 kHz). Furthermore, the electrode effects almost fall. For high-resistance objects, it is recommended to create closed-type electrochemical cells.

1:25 p.m.	T. Bubela, V. Yatsuk, M. Mykyjchuk, Y. Yatsuk (UA-Lviv)

Non-dismantling control possibilities of distributed systems measuring channels in-situ operation place

To implement the concept of the European metrological cloud in distributed measuring devices, it is necessary to correctly carry out the non-dismantling calibration of the measuring channels at the place of operation. At the same time, it is advisable to separately calibrate the sensors and measuring channels of the distributed measuring means, starting from the sensor output and ending with the technical means for displaying of the measured quantity values for a given configuration of the entire measuring circuit.

In this work, for on-site calibration of low-level direct current voltage measuring channels, it is recommended to use portable calibrators with automatic additive error component correction. The error correction principle is to modulate, transform and demodulate the voltage of the reference voltage source. The issue of the possibility of implementing the voltage calibrator as an integrated microcircuit was discussed. Their used possibilities for the calibration of measuring channels of distributed systems on-situ exploitation are discussed. It is shown that the limit value of the uncorrected additive error component for modern elements will be several tens of nanovolts.

1:30 p.m.	Zhi Li (D-Braunschweig), U. Brand, R. Popadic, K. Hiller, S. Hahn (D-Chemnitz), E. Peiner, E. Gärtner, J. Frühauf (D-Limbach-Oberfrohna)

Small force metrology for AFM, stylus instruments, CMM and nanoindenter via reference springs and sensors

2:00 p.m. – 2:20 p.m. Coffee break and visits of expositions

3:15 p.m. Start excursion to Erfurt

Session 1.2 Nanofabrication

Time: Wednesday, 06.09.2023
Location: Humboldt building, Lecture room 211/212
Chairman: T. Kissinger (D-Ilmenau)

9:00 a.m.	T. Busani, I. Stricklin (US-New Mexico), I. Rangelow (D-Ilmenau)

Multifunction probes approach to integrate atomic metrology with analog/digital lithography and near field spectroscopy

As transistors are reaching the size of few atoms, metrology and lithography has become extremely challenging and equally critical. This drives the development of a new set of tools and techniques both in metrology and lithography. Those techniques are built to serve a new generation of lithographic and metrology systems with the same goals of the system they came before them: insuring control, precision and confidence in the fabrication process.

Our approach to this problem is the fabrication of a Multipurpose Atomic Force Microscopy (MAFM) probe that integrates UV lithography, field emission lithography and digital lithography in a single system that allows patterning generation with atomic accuracy, real time inspection with atomic resolution and micro Raman Spectroscopy.

The MAFM shows a 365 nm laser emission with 1.5 nm FWHM, lithography patterning as small as 7 nm in field emission lithography configuration and 2 atom lithography in scanning tunneling mode. Furthermore, GaN NWs with aspect ratios up to 100 allows deep trenches measurements.

The MAFM offers the functionality and versatility of several incumbent technologies in one single, system that conventional materials (W, diamond, SiN3 and Si) can't provide.

9:20 a.m.	T. Ma, M. Fahrbach, J. Xu, M. Vergin, A. Waag, E. Peiner (D-Braunschweig)

Imaging the mechanical properties of nanowire arrays Dimensional and contact

Dimensional and contact resonance (CR) images of nanowire (NW) arrays are measured using our new-developed CR imaging (CRI) setup. Then a reference method is employed to calculate the indentation modulus of NWs (Mi,NW) representing the elasticity of NWs, by measuring NW arrays (NWAs) and reference samples at the same static probing force. Furthermore, topography is imaged in combination with CR and Mi,NW separately by software, whereby the relation between both parameters of NWAs is visualized. As typical examples, 3D imaging of topography and Mi,NW is performed with Si<111> pillar, Cu and ZnO NWAs. The novel method allows for fast mechanical performance measurements of large-scale vertically-aligned NW arrays (NWAs) without releasing them from their substrates.

9:40 a.m.	J. Stauffenberg, J. Belkner, J. Ruprecht, I. Ortlepp, E. Manske (D-Ilmenau)

Tip-based nanofabrication and nanometrology in combination with a planar nanopositioning machine (NFM-100)

In this paper, the focus is on the combination of a nanopositioning machine and tip-based technology. The range of motion of the planar machine allows macroscopic surface scanning by atomic force microscopy (AFM) as well as the fabrication of nanostructures by field emission scanning probe lithography (FESPL), which considerably extends the usual ranges of motion of tip-based systems on wafer sizes up to 4 inches. The use of active microcantilevers allows easy switching between measuring and writing modes, eliminating the need for tool changes or realignment and allowing structures to be analysed immediately after fabrication.

The applicability of tip-based technology for macroscopic working areas through the combination with nanopositioning machines is discussed in this work.

Results are shown in form of long-range AFM line scans, where the microcantilever performs the z-motion and the positioning in the x-y-direction is realised by the machine table of the NFM-100. Furthermore, in addition to the fabrication of line widths below 40 nm, the fabrication of nanostructures over lengths in the mm-range is demonstrated and analysed with regard to accuracy.

10:00 a.m.	A.S. Huaman, J. Reger (D-Ilmenau)

Robust adaptive tracking control for highly dynamic nanoprecision motion Systems

This abstract focuses on the design and real-time implementation of advanced control strategies for motion systems with highly dynamic nanopositioning capabilities. The key exemplar is the lifting and actuating unit (LAU), which integrates a pneumatic actuator for weight force compensation and a parallel electromagnetic drive to produce precision motion forces. Initial investigations cover the modeling and parametric identification of the overactuated nature of a single LAU. This lifting module, integrated into a test bench, renders a 1D vertical motion system aimed to perform subnanometer positioning tasks while minimizing heat emission. To this end, we propose a control allocation strategy to assign (zero-mean) high-dynamic forces to the electromagnetic channel, producing a very low heat emission while the performance is fulfilled using an LQ-type controller plus an L1 adaptive augmentation. This investigation closes with RMS positioning errors less than 0.25 nm and electrical currents less than 0.30 mA. Further investigations involve a 3D tilt-and-lift vertical motion system integrating three LAUs, each placed in each corner of a triangular payload. The key challenge of

this configuration is to cope with the high cross-couplings between the degrees of freedom (DOF), i.e., vertical and rotational motion. The core of the decoupling task is the nominal LQG-type controller comprising disturbance-rejection-based observers aimed to fully compensate cross-couplings, while the L1 adaptive augmentation recovers the nominal performance in the presence of parametric uncertainties w.r.t. the input gain. Given that the heat emission problem is fully solved for a single LAU, we then focus on the performance and robustness of the 3D closed-loop system. Since full-state information of the cross-couplings is not simple to reconstruct, we adopt the output-feedback control architecture for the nominal controller and L1 adaptive augmentation. The effectiveness of the proposed control strategy is verified via real-time experimentation rendering vertical RMS positioning errors of less than 0.25 nm and RMS rotational errors of less than 0.04 μrad while satisfying the heat emission constraint. The investigations conclude by exploring the outstanding performance/robustness trade-off of the L1 adaptive control theory for a nanometer planar positioning system with a travel range of ø200 mm (i.e., NPPS200) and the subsequent integration with the 3D vertical motion system, thereby transitioning to a full 6D system (i.e., NPPS200-6D) with 25 mm vertical stroke. Within this framework, the complexity of the controller design is higher because of the number of DOF, cross-couplings, external disturbances, and parametric perturbations. We completed our investigations through experimental validation with planar and vertical RMS positioning errors of less than 0.80 nm and RMS rotational errors of less than 0.05 μrad, as shown in Figure 1.

10:20 - 10:40 a.m. Coffee break and visits of expositions

10:40 a.m.	R. Knechtel (D-Schmalkalden), U. Schwarz (D-Erfurt)

Wafer bonding technologies for nano-, micro- and macro-system realization and integration

This paper is providing an overview about most common wafer bonding technologies used for the realization of nano-, micro,- and macro systems and for system integration. At first, the general aspects of wafer bonding applications are discussed. This is followed by the technological description of different wafer bonding processes, since for different bonding applications different processes are required related to process integration and the actual surface layers on the wafers which should be bonded. Finally, benefits and drawbacks as well as technology systematization and detailed comparison of the described bonding processes. This overview should help to choose the best suitable process for wafer level bonding and other applications.

11:00 a.m.	K. Lauer, C. Möller, S. Reiß, E. Hiller, T. Ortlepp (D-Erfurt), A. Flötotto, K. Peh, D. Bratek, R. Müller, D. Schulze, S. Krischok, W. Beenken, E. Runge (D- Ilmenau)

Defect-engineering for better silicon devices based on understanding of the A_{Si}-Si_i-defect

Defects in silicon have a variety of positive and negative consequences. For example, they can accept or donate mobile charge carriers and hence influence the conductivity of the silicon. Often, they reduce the lifetime of excess charge carriers. Defect-engineering procedures and thus also a detailed knowledge about the occurring defects are of utmost importance for improving devices such as silicon solar cells, insulated-gate bipolar transistors (IGBT) and low-gain avalanche detectors (LGAD).

A particularly challenging class of defects, the so-called ASi-Sii-defects ("ASi": substitional acceptor atom, "Sii": silicon self-interstitial), has been thoroughly investigated in the last decade in close cooperation by the CiS Erfurt and the TU Ilmenau.

In this contribution, we summarize how this defect affects the functionality of silicon devices such as LGADs or silicon solar cells. We show how the defect kinetics can be understood based on a ASi-Sii-configuration coordinate diagram proposed by us in earlier work [for a review, see K. Lauer et al, phys. stat. sol. A 219, 2200099 (2022)] and how the defect kinetics affects the device properties. In particular, we discuss in detail how the well-known light-induced degradation (LID) of silicon solar cells can be explained using our ASi-Sii-defect model.

Finally, we discuss some strategies how the detrimental effect of the ASi-Sii-defect on some silicon-device performances can be circumvented by defect-engineering.

11:20 a.m.	H. Nguyen, G. Apte, M. Soter, D. Madkatte (D-Heiligenstadt)

Insights into the writing process of the mask-free nanoprinting fluid force microscopy technology

Platelets are activated immediately when contacting with non-physiological surfaces. Minimization of surface-induced platelet activation is important not only for platelet storage but also for blood-contacting devices and implants. Chemical modification tunes the response of cells to contacting surfaces but it requires a long process involving many regulatory challenges to transfer into a marketable product whereas biophysical modification overcomes the limitation via modifying only the surface topography of already approved materials. Available large and random structures do not cause a significant impact on platelets because of their

smallest size (only 1-3 μm) compared to other cells. We have recently demonstrated the feasibility of the mask-free nanoimprinting Fluid force microscope (FluiFM) technology in printing gid and hexanol structures. Here, we demonstrated that the technique allows to fabricate nanostructured surfaces of varying features. Characteristics of nanostructures including height, width, and interspaces were analyzed and compared using atomic force microscopy imaging. Based on the results, we identified several technical issues such as printing direction and designed shapes that directly altered nanofeatures during imprinting. We confirmed that FluidFM is a powerful technique to precisely fabricate a variety of desired nanostructures for the development of platelet/blood-contacting devices if technical issues during printing are well controlled.

11:40 a.m.	M. Rodenberg, L.J. Münker, R. Tutsch, P.J. Walla, T. Weimann (D-Braunschweig)

A STORM of blinking molecules: using super-resolution microscopy to image fluorophore-doped photoresist structures

Photoresists play a key role in the photolithographic process being necessary to print the structure layout of dies of microchips. Following Moore's law leads to ever smaller assemblies reaching the single-digit nanometer range. Typical meth-ods for quality assurance are scatterometry and atomic force microscopy facing challenges and disadvantages. Since overcoming the Abbe limit via superresolu-tion techniques fluorescence microscopy can be another approach. This article describes the measurement analyses done with PALM/ STORM on lithographical produced samples of positive resist doped with Atto 565. Lines with 200 nm thickness and equal spacing were studied. Thereby, ThunderSTORM provided better results than QuickPALM for data analysis. For the first experiment, using a permanently switched on 405 nm laser beam with low intensity shows the best resolution results. A rotating lambda half-wave plate in the second experiment leads to a slight increase of data quality. Further studies combining these two approaches will be carried out.

12:00 noon – 1:00 p.m. Lunch and visits of expositions

Session 1.3 Measurement and sensor technology

Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture hall (HU-HS)
Chairman: T. Fröhlich (D-Ilmenau)

1:30 p.m.	R. Oliveira (BR-Rio de Janeiro), P. Weidinger, Z. Song, J. Sander, D. Mirian (D-Braunschweig)

Overview of current EMPIR research projects for the non-static traceability of mechanical quantities

Industry is facing various challenges in important themes of the society, such as Energy, Mobility, Sustainability and Environment. Metrology is a crucial pillar for reaching reliable production, efficiency, regulation and innovation. New tasks and challenges are in the current discussion metrological scenario and, looking specifically to the quantities Force and Torque, there is an enormous necessity to solve the gap between static traceability and dynamic use of the sensors.

The transducers used in regimes under non-static measurement have traditionally tracked their calibration and verification methods to a series of standards, tools and equipment that are metrological consolidated with a given uncertainty level, but still based on static principles.

In this direction, two European Metrology Programme for Innovation and Research (EMPIR) projects, shortly named ComTraForce and WindEFCY, aimed to study the static versus the non-static relationship in the use of force and torque measurement systems and the necessary actions to achieve adequate traceability and how that impacts the Metrological Quality Infrastructure.

1:50 p.m.	S. Schulze, R. Theska, (D-Ilmenau), K. Arumugam, G. Shaw (US-Gaithersburg)

Development of a high precision balance for measuring quantity of dispensed fluid as a new calibration standard for the becquerel

The 2019 redefinition of the kilogram not only changes the way mass is defined but also broadens the horizon for a direct realization of other standards [1]. The True Becquerel project at the National Institute of Standards and Technology (NIST) is creating a new paradigm for realization and dissemination of radionuclide activity. Standard Reference Materials for radioactivity are supplied as aqueous solutions of specific radionuclides which are characterized by massic activity in the units becquerel per gram of solution, Bq/g [2]. The new method requires measuring the mass of a few milligrams of dispensed radionuclide liquid. An electrostatic force balance is used, due to its suitability for a milligram mass range [3]. The goal is to measure the mass of dispensed fluid of 1 to 5 mg with a relative uncertainty of less than 0.1 % for $k = 2$. A description of the balance's operation and results in measuring a reference mass show the feasibility of this method.

2:10 p.m.	M. Wittke, M. Torres Melgarejo, M. Darnieder, R. Theska (D-Ilmenau)

Investigation of a novel monolithic stiffness-compensated mechanism for high-precision load cells

Increasing demands in the fields of high-precision force measurement and weighing technology require an ever-higher measurement resolution, a larger measurement range, a lower measurement uncertainty, and traceability to a natural constant. Load cells using the compensation principle have the potential to fulfill these requirements. To enhance the measurement resolution and decrease the measurement uncertainty, the residual stiffness of the compliant mechanism in use needs to be compensated.

Due to a lack of solutions in the state of the art, a novel monolithic stiffness-compensated mechanism for measurements according to the compensation principle was developed. Simulations show a stiffness reduction to 0.2% of the initial value, a theoretical force resolution of 31 pN, and applicability for any orientation in the gravity field. Experimental investigations on a prototype confirmed the existing potential. However, further optimization of the mechanism is required to negate the effects of manufacturing deviations.

2:30 p.m.	P. Fleischmann (D-Stuttgart), J. Happel (D-Stockach), B. Gundelsweiler (D-Stuttgart)

Analysis and development of a sensor concept for multi-stable actuators with passive magnetic shape memory alloy

Due to the increasing demand for energy efficient and highly integrated drives, novel actuator concepts are gaining steadily in interest. The passive use of magnetic shape memory alloys as smart damping elements can meet both of these requirements. Using the internal friction and strain-dependent permeability of magnetic shape memory alloys, it is possible to transform conventional actuators into multi-stable, energy-efficient drives with self-sensing capabilities. The sensor concept presented converts the strain-dependent permeability of the magnetic shape memory alloy into an inductance change via a sensor coil arrangement. The change in inductance of the sensor coil is converted into a change in the resonant frequency of a parallel oscillating circuit. A microcontroller detects the resonant frequency of the circuit and converts it into a position sensor signal. To verify the functionality of the sensor, a test rig is developed that deforms the magnetic shape memory element under realistic application conditions. Experimental measurements in a climate chamber are used to evaluate the performance and characteristics of the sensor. Finally, it is demonstrated that the presented sensor concept can be used to determine the position of passive magnetic shape memory alloy actuator.

2:50 – 3:10 p.m. Coffee break and visits of expositions	
3:10 p.m.	J.A. Calderon Chavarri, E.B. Barriga Gamarra, J.C. Tafur Sotelo, J.I. Leon, J. Lozano, H. Lozano, R. Gallo, J. Zena (PE-Lima)

Wireless intelligent sensors based in nanostructures with energy self-sufficiency to study the consequences of high temperatures in combustion motors

In this research are proposed the consequences of high temperatures in Internal Combustion Motors (ICM) as correlation of its performance according to give information of the ICM fault detector, which also can be useful for preventive maintenance. It was possible to achieve the proposed target because of it was designed a smart sensor based in nanostructures prepared over Anodic Aluminum Oxide (AAO) samples, which proportionated short response time and high robustness in the measurement tasks of the smart sensor, as well as, the designed sensor has the possibility to work by energy self-sufficiency and sending the measurement data to external users by wireless. In fact, it is waited that this research could be a support for researchers of ICM enhancement, who could look for new techniques of environment conditions cares in compensation to keep the balance between the useful energy obtained from ICM and the environment conditions, where are developed economical activities such as public transport or mining in Peru.

3:30 p.m.	J. Chauhan, S. Gourishetti, S. Grollmisch, M. Rohe, M. Sennewald, J. Hildebrand, J.P. Bergmann (D-Ilmenau)

Empirical study on DED-Arc welding quality inspection using airborne sound Analysis

This research investigates the potential of utilizing audible range airborne sound emissions to develop an automated classification system using neural networks. The objective is to detect and classify irregularities in the Gas Metal Arc Welding (GMAW) process, specifically targeting the presence of oil or insufficient shielding gas coverage, which contribute to porosity imperfections in weld seams. A laboratory setup was created to produce aluminium and steel wall structures using Directed Energy Deposition-Arc (DED-Arc) based additive manufacturing, with varying shielding gas flow rates and oil as a contaminant. Acoustic emissions (AE) during the welding process were recorded using microphones capturing audible to ultrasonic range frequencies. Mel spectrograms were computed from the AE data for input in training the neural networks. To mitigate data scarcity, various data augmentation techniques were employed. The proposed classification model achieved an accuracy of 83% for binary classification and 68% for three-class classification on aluminium weld seams. For steel weld seams, the accuracies

were 82% for binary classification and 58% for three-class classification. These results indicate that utilizing AE and deep neural networks in the GMAW process monitoring is a viable method for low-latency monitoring and provides valuable insights for improving weld seam quality. Moreover, this approach paves the way for future advancements in related areas.

3:50 p.m.	O. Bader, N.E.B. Amara (TN-Sousse), O. Kanoun (D-Chemnitz)

Evaluation of 3D current injection patterns for human lung monitoring in electrical impedance tomography

Electrical impedance tomography (EIT) is a non-invasive imaging technique for monitoring the lungs continuously. During EIT Measurements, currents propagate intrinsically in 3D, since electrical current propagates diffusely in the human tissues, so a 2D EIT remains not sufficient to study the out-of-electrodes plane effects on the images. Until now, not enough effort has been made to evaluate the performance of 3D measurement patterns for lung monitoring. In this paper, to investigate 3D current injection patterns for 3D EIT, a 3D model mimicking the geometrical and electrical characteristics of the human thorax has been developed based on Finite Element Method (FEM) along with the Complete Electrode Model (CEM). Simulations have been performed with aligned ("planar," "zigzag", "square", "zigzag opposite", and "planar opposite"), and offset ("planar offset", and "zigzag offset") current injection patterns. Analysis shows the greatest current density diffusion results using the "zigzag opposite" current injection pattern.

4:10 p.m.	H. Alasasfeh, O. Kanoun (D-Chemnitz), M. Hafsa, O. Bader (TN-Sousse)

Machine learning approach for the image reconstruction of the human forearm section at different hand signs

Electrical impedance tomography (EIT) is an imaging technique used to reconstruct the conductivity of a target object based on a boundary voltage resulting from the injection of AC signal using boundary electrodes placed on the object's surface. In this study, we investigate suitable image reconstruction algorithms for Electrical Impedance Tomography (EIT) to enable the reconstruction of the conductivity distribution in the forearm section inferring muscle contractions at different hand signs. As EIT image reconstruction is an ill-posed inverse problem, the Gauss-Newton algorithm needs many iterations for the determination of suitable values of the regularization parameter and corresponding calculations of the Jacobian matrix. To reduce computational effort, we propose to use machine

learning algorithms to directly reconstruct the EIT image. We explore the Radial Basis Neural Network (RBNN) and a one-dimensional Convolutional Neural Network (1D-CNN), which has been trained based on the measured EIT data for eight subjects, ten hand signs with ten trials. Both methods reach a low deviation at 0.0017 for RBNN and 0.0109 for CNN.

End of Session

Session 1.4 Precision engineering and optics

Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 129
Chairman: R. Theska (D-Ilmenau)

1:30 p.m.	R. Hebenstreit, R. Theska (D-Ilmenau)

Calibration of positioning microsystems with subatomic accuracy

Multidimensional positioning, measuring and manipulation with a spatial resolution in the subatomic range are an upcoming demand in nanotechnology. Nanopositioning and measuring machines (NMM) enable to measure and manipulate objects within a large addressable 3D-range of up to a few hundred millimetre in each dimension with a specified spatial resolution of down to 0.1 nm. New approaches are needed to extend the potential of NMM technology to even smaller scales. In previous work a proof-of-concept positioning system has been designed to achieve reproducibility and resolution for precise motion on subatomic scale. In a first approach, a scanning probe microscope (SPM) will be used to measure a nanosized periodic lattice that serves as a scale for the position. Here, we present a microsystem design with an addressable positioning range of ± 100 µm that will carry the lattice structure. In order to precisely control the motion, the electrostatic drive and position sensor characteristics of the demonstrator must be calibrated thoroughly by means of an optical measuring system. A focused, range-resolved fibre-optic laser interferometer is comprised as the calibration standard. An uncertainty estimation for the measurement setup is carried out. It is shown that the desired positioning accuracy for the first tip- and grating-based setup can be achieved with the presented microsystems.

1:50 p.m.	S. Linß (D-Ilmenau), T. Erbe (NL, Eindhoven)

Flexure hinge-based lens manipulators – a concept survey

A typical, but still challenging application of compliant mechanisms with flexure hinges are lens manipulators. Especially in high precision optical systems those are common means to correct optical imaging errors.

The requirements for lens manipulators with respect to the resolution of motion are in the order of nanometres and nanoradians. The kinematic concepts and embodiment considerations of manipulators are proprietary knowledge of the companies using them and there is almost no literature about general design considerations available. However, general kinematic principles can be found in patents and used to compare their underlying compliant mechanisms.

Therefore, this paper presents a survey of certain kinematic manipulator concepts based on existing patents. The resolution and range of motion of the manipulators are estimated and put into perspective in the context of lens manipulation. The comparison of identified kinematic concepts is used to emphasize aspects of

practical implementation and embodiment design of flexure hinges in lens manipulators.

2:10 p.m.	M. Miettinen, R. Viitala, P. Haverinen, O. Leutonen, V. Vainio (FL, Espoo), R. Theska (D-Ilmenau)

Validation of experimental setup for aerostatic bearing simulation

Aerostatic bearings are extensively used in precision engineering applications that require high positional accuracy and low friction motion. In these bearings, externally pressurized gas is fed through a restrictor into the bearing gap. The viscous shear in the gap restricts the flow, thus forming a pressurized film between the bearing and the guide surface. In the development of models and in investigations of, for example, effects of manufacturing errors and porous material permeability properties, characterization of bearing performance is required. The performance is commonly characterized with a measurement setup, either under static or dynamic conditions. In the present study, an experimental setup for the measurement performance of aerostatic bearings is presented. The investigated measurement setup is validated with a comparison to a literature model.

The results of the present study include the load capacity, stiffness, air consumption and pressure distribution of a commercially available axisymmetric graphite thrust bearing. The results show good agreement between the measurements and the model. Thus, the results show corroborative evidence on usability of the measurement setup in future aerostatic bearing research.

2:30 p.m.	F. Pollinger, G. Prellinger (D-Braunschweig), M. Krauhausen, R. Priem (D-Aachen)

High-resolution absolute range sensors based on the combination of frequency modulation synthetic wavelength interferometry and laser triangulation for heavy industry applications

Feedback control of metal strip rolling processes requires inline-capable, fast and robust thickness gauges. An optical thickness gauge is developed which measures the distance to the top and bottom of the strip with two optical sensors. They combine triangulation and multi-wavelength interferometry for a robust absolute high-resolution range measurement. Sinusoidal modulation interferometry is used to realize a very compact fiber optics-based Fizeau-type multi-wavelength interferometer. Field Programmable Gate Arrays (FPGA) enable a performant digital lock-in, subsequent fusion of triangulation and interferometric data, and real-time thickness analysis. Gauge blocks are used for on-site calibration . The performance of the thickness gauge is studied in the laboratory. A simulation experiment provides dynamic conditions of strip transport speeds between 40 and 200 m/min that are close to production environment. The results show a convincing

qualitative and quantitative agreement between optical and tactile gauges.
Features in the order of 100 nm and below are consistently resolved by both gauges. The average thickness is observed to deviate up to 300 nm between the two gauges, possibly due to different physical sensor principles, but also due to inevitable thermal drifts. The expanded measurement uncertainty of 0.48 μm of the system is nevertheless well consistent with these deviations. The optical gauge hence delivers the targeted performance under heavy industry conditions.

2:50 – 3:10 p.m. Coffee break and visits of expositions

3:10 p.m.	F. Weigert, M. Wolf, R. Theska (D-Ilmenau)

Development of a tool-changing system for nanofabrication machines

The frequent use of a growing diversity of tools in nanofabrication machines raises the need for a highly reproducible tool-changing system that is capable of working with tools of different weights and moments of inertia. Since the tool-changing system is designed beneficially based on an open, force-paired kinematic coupling, means to apply a holding force are required. The holding force has to be applied without heat dissipation or other disturbances. Since variations in the elastic deformation at the contact points of the coupling directly influence the reproducibility of the tool position, the force application needs to be highly reproducible. An analytical model is developed to determine the force application requirements considering elastic deformation and friction. Based on this model, the allowable variation of the holding force in amount and direction, as well as the allowable deviation of the force application point, are determined. Thereby, the resulting influence of the force application on the reproducibility of the position of the tool-center point is intended to be 5 nm or less. Eleven solution principles for force application are developed based on the physical effects of magnetic force, spring force, and weight force. Based on a systematic evaluation, an arrangement of three permanent magnets with flux guide pieces at an angle of 120° to each other has been chosen. The designed prototype will be tested and further optimized within a nanofabrication machine.

3:30 p.m.	C. Hahm, R. Theska (D-Ilmenau), T. Erbe (NL)

Cement-bound mineral casted parts in precision engineering

The design of the machine frame, supporting a plurality of components/modules, is a major challenge during the development of precision systems. The geometric stability of the supporting parts under thermal and mechanical loads has a decisive influence on the achievable accuracy. Common materials like cast iron or natural stone, have preferable properties but often come with high costs and long lead times due to sourcing/manufacturing process and required geometric precision.

Concrete is an interesting alternative. Polymer concrete and cement-based concrete like self-compacting concrete is considered for quite some time as cost-effective alternatives.
This contribution summarizes recent research and findings from literature of those alternative materials and reflects on the status for use in machine frame designs. This will address aspects of cold primary shaping process emphasizing ready-to-use features with tight geometric tolerances as well as the possibility to integrate functional elements in the light of lot- and part-related costs. The advantages of concrete as an alternative material are summarized with regard to the application of the design principle of "functional material at the functional location".

3:50 p.m.	M. Layher, J. Bliedtner (D-Jena), R. Theska (D-Ilmenau)

A laser beam deflection system for heat treatments in large scale additive manufacturing

The laser beam deflection system consists of a combination of an elliptical, tube-like mirror with an additional, rotatable flat mirror in one of its focal axes. The deflected laser beam hits the second focal axis where the extruder nozzle is located. Thus, > 75% of the nozzle circumference is covered during a laser beam treatment. Both mirrors are individually designed custom-made parts. Mirror surfaces are manufactured via ultraprecision diamond turning. The realization of the elliptical shape is accomplished by means of a multi-axis-turning machine. After the implementation and alignment of the system, a good agreement of the performance with the simulation results could be demonstrated. In addition to the beam guidance along the printing path, a superimposed oscillating movement can also be realized. This enables dynamic temperature control and thus homogenization of the irradiation. Therefore, simultaneous heat treatment of the underlying and adjacent strands becomes possible. The opto-mechanical system represents a new approach in enhanced additive manufacturing as well as an extension of the state of the art. The functional verification lays the foundation for an improved additive manufacturing process, which aims to homogenize the component structures to improve the mechanical properties of 3D-printed components.

End of Session

Session 1.4 Precision engineering and optics

Time: Wednesday, 06.09.2023
Location: Humboldt building, Lecture room 129
Chairman: R. Theska (D-Ilmenau)

9:00 a.m.	M. Torres Melgarejo, S. Henning, L. Zentner, R. Theska (D-Ilmenau)

Synthesis of optimized compliant mechanisms for ultra-precision applications
Compliant mechanisms for ultra-precision applications are often required to achieve highest accuracy over largest possible ranges of motion along multiple axes. The typical synthesis approach for such high demands is based on the substitution of the revolute joints of a suitable rigid-body model with optimized flexure hinges. However, during the transition from rigid-body model to compliant mechanism, the effects of multiple input parameters are still widely unknown. Among them are the degrees of freedom of the rigid-body model, the integration of the drive elements, as well as the coupling of mechanisms to achieve multiple motion axes. The following contribution expands the fundamentals of the synthesis of compliant mechanisms based on rigid-body models for their application in ultra-precision technologies. Based on the investigation of the aforementioned parameters as well as the knowledge gained from previous research work, a novel synthesis method has been developed.

9:20 a.m.	V. Vainio, J. Majuri, M. Miettinen, P. Haverinen, O. Leutonen, R. Viitala (FL-Espoo)

Aerostatic deflection compensation for flexible large-scale rotor
In cardboard and paper manufacturing, the paper web is handled with large scale rolls. From the machine design point of view, those rolls are large rotors with high stiffness, accuracy and balance requirements. In paper machines, the rotors not only guide the web but also are used to perform different treatments for the manufactured product. In the cases where highest load and straightness is required, deflection compensated rolls are applied. Commonly, deflection compensated paper machine rolls consist of stationary axle in the middle of the roll and hydrostatically supported rotating shell. Main downside of the traditional deflection compensated roll is high energy consumption. High friction occurs in the hydrostatic system supporting the rotating shell. In this research, test device was built to perform conceptual investigation of suitability of aerostatic bearings to be applied in the deflection compensated rolls. Porous material aerostatic bearing

was built in concave shape to interact with the shell of a roll. The bearing design was a combination of a bearing and a sealed chamber restricted with the bearing itself from the ambient. Air consumption, load and drive motor current were measured at various rotating speeds. The results of the research show the performance of the investigated bearing at various operating parameters, from which the point of highest performance can be determined. The results suggest that the porous material based aerostatic bearings as a technology is feasible to be applied in the deflection compensation systems. The validation of the feasibility of the concept of the aerostatic deflection compensation enables further investigations into optimizing the performance of the system for widespread utilisation.

9:40 a.m.	D. Schaeffer, D. Klenkert, J. Stauch, M. Kufner, R. Foerg, J.Ebbecke (D-Deggendorf)

Fabrication of asymmetric multimode splitters in glass by planar ion exchange and laser ablation

The fabrication of planar lightwave circuits (PLC) using the laser-ablated ridge waveguide technique is explored. In particular, asymmetric multimode splitter structures are designed and fabricated. The experimental work is accompanied by modeling the relevant parameters. An ion exchange model determines a suitable set of ion exchange duration, temperature, electric field, and ridge geometry. In the simulation, special attention is paid to a good match of the waveguide shape between the PLC components and commercially available GRIN fibers.

Wave-optical simulations of the light propagation in the PLC devices are performed using a scalar beam propagation method. Based on the simulation, asymmetric splitter devices are designed for a variety of splitting ratios. A 70:30 splitter is fabricated and attached to optical fibers for characterization. As indicated by a low excess loss, low intrinsic waveguide losses are achieved. The experimental splitting ratio of 71:29 is in good agreement with the simulation.

10:00 a.m.	M. Darnieder, M. Wittke, R. Theska, M. Pabst, T. Fröhlich (D-Ilmenau)

Monolithic compliant mechanism for an EMFC mass comparator weighing cell

Mass comparator weighing cells based on electromagnetic force compensation (EMFC) find application in the most demanding force and mass measurement applications. The centerpiece of these devices is a highly sensitive compliant mechanism with thin flexure hinges. The compliant mechanism forms the mechanical part of the mechatronic overall system. A novel mechanism based on an advanced adjustment concept has been developed, manufactured, and experimentally investigated. The adjustment is designed to further reduce the measurement uncertainty for mass comparisons by canceling out first-order error

components. The focus is on the mechanical properties: stiffness, tilt sensitivity, and off-center load sensitivity. The elastic stiffness of the compliant mechanism is compensated by introducing a negative gravitational stiffness to enable the compensation of manufacturing deviations and to increase mass resolution.

10:20 - 10:40 a.m. Coffee break and visits of expositions

10:40 a.m.	T. Erbe (NL-Veldhoven)

Basic considerations for circumferential adhesive bonds in order to reduce lens deformations

A critical aspect of designing lens mounts is to minimize lens deformation, since shape and position of the optical elements determine the performance of an optical system. The mounting of the lens to the lens-cell is a major contributor to lens deformation and therefore of particular interest during the design – of the lens-mount as well as the lens itself.

A common technology used for lens mounting is the circumferential adhesive bonding. The adhesive system of lens-cell, lens, selected adhesive has been discussed in the literature predominantly focussing in minimizing forces on the lens at different temperatures by defining a optimized glue gap. However, these models are not always applicable due to volume constraints, technological restrictions and/or the different dimensions of lenses.

Therefore this paper will focus on minimization of the effect of these forces by the design of the adhesive bond rather than reducing the amount of force itself. By applying straight robust design principles a rather simple way to minimize lens deformation for common lens mount concepts will be presented.

11:00 a.m.	L. Zettlitzer, H. Gross, S. Riesse (D-Jena), R. Theska (D-Ilmenau)

Tolerancing aspects of a reflective dual field-of-view optical system based on Alvarez-Principle

This article presents a dual-state reflective optical system for space remote sensing, based on an adapted Alvarez concept. Using the solution found, two different object fields can be imaged using the same optical system. A Three-Mirror-Anastigmat telescope (TMA) is proposed with an intermediate image plane that incorporates a double reflective freeform subsystem as a relay system. By mechanically moving two freeform mirror substrates, this subsystem allows for a discrete change in the total focal length. A deep understanding of the effects of geometric deviations on the system is a crucial prerequisite for ensuring mechanical feasibility and stable optical imaging performance. For this reason, this paper focuses on the method and results of tolerancing the system.

11:20 a.m.	L. Keck, F. Seifert, D. Newell, D. Haddad (USA- Gaithersburg), R. Theska (D-Ilmenau)

Preliminary Characterization of Anelastic Effects in the Flexure Mechanism for a new Kibble Balance at NIST

A new Kibble balance is being built at the National Institute of Standards and Technology (NIST). For the first time in one of the highly accurate versions of this type of balance, one single flexure mechanism is used for both modes of operation: the weighing mode and the velocity mode. The mechanism was the core part of the new balance design because it is a paradigm shift for NIST away from using knife edge-based balance mechanisms, which exhibit hysteresis in the measurement procedure of the weighing mode. Mechanical hysteresis could be a limiting factor in the performance of highly accurate Kibble balances approaching single digit nanonewton repeatability on a nominal100 g mass as targeted here. Flexure-based mechanisms are known to have very good static hysteretic properties when used as a null detector, however, for larger and especially longer lasting deformations, they are known to exhibit anelastic drift. We seek to characterize and ideally compensate for this anelastic behavior after deflections during the velocity mode to enable the measurement of a nominal100 g mass artifact with a relative uncertainty of 〖10〗 ^(-8) by use of a single flexure-based balance mechanism.

11:40 a.m.	M. Darnieder, M. Wittke, R. Theska, M. Pabst, T. Fröhlich (D-Ilmenau)

Monolithic compliant mechanism for an EMFC mass comparator weighing cell

Mass comparator weighing cells based on electromagnetic force compensation (EMFC) find application in the most demanding force and mass measurement applications. The centerpiece of these devices is a highly sensitive compliant mechanism with thin flexure hinges. The compliant mechanism forms the mechanical part of the mechatronic overall system. A novel mechanism based on an advanced adjustment concept has been developed, manufactured, and experimentally investigated. The adjustment is designed to further reduce the measurement uncertainty for mass comparisons by canceling out first-order error components. The focus is on the mechanical properties: stiffness, tilt sensitivity, and off-center load sensitivity. The elastic stiffness of the compliant mechanism is compensated by introducing a negative gravitational stiffness to enable the compensation of manufacturing deviations and to increase mass resolution.

12:00 noon – 1:00 p.m. Lunch and visits of expositions

Elevator pitches 1.4 Precision engineering and optics

Time: Wednesday, 06.09.2023
Location: Humboldt building, Lecture room 129
Chairman: R. Theska (D-Ilmenau)

1:00 p.m.	Y. Hirniak, O. Ivakhiv (UA-Lviv), P. Nevodovskyi, A. Vidmachenko, M. Geraimchuk, O. Zbrutskyi (UA-Kyiv)

Developing of the space satellite-based polarimeter

As the part of the ecological space mission the ultraviolet polarimeter is planned to be installed on the observing satellite that would work on the lower orbit. The main task of this device is the aerosol density monitoring in the top layer of atmosphere with the remote analysis of the gathered data on land. The implementation of the planned experiment requires the development, creating and installation of the ultraviolet polarimeter onboard of the microsatellite platform. This device must be compact and lightweight and fully autonomous in the automatic mode. So, aside from the sensitive measuring parts the efficient control system need to be developed as well. This ultraviolet polarimeter is a passive optoelectronic device that can remotely acquire polarimetrically sensed data. It is the one-point single-channel ultraviolet polarimeter with rotated polarizing element.
Currently developed operating UV polarimeter model can do the following operations:
- gathering photosensor polarimetric information,
- gathering thermosensors information,
- sending measured data to the PC through USB interface, and storing in the MS Access database via specially designed PC application,
- functioning in fully automatic or manually controlled working modes with the remote control.

Developed operating model of the UV polarimeter currently provide valuable experience of working with the all the units and possibilities to analyze the system performance.

1:05 p.m.	V. Vainio, O. Leutonen, P. Haverinen, M. Miettinen, J. Majuri, R. Viitala (FI-Espoo)

Aerostatic bearing for large rotor

In cardboard and paper manufacturing, the paper web is handled with large scale rolls. From the machine design point of view, those rolls are large rotors with high stiffness, accuracy and balance requirements. In paper machines, the rotors not only guide the web but also are used to perform different treatments for the manufactured product. In the cases where highest load and straightness is required, deflection compensated rolls are applied. Commonly, deflection compensated paper machine rolls consist of stationary axle in the middle of the roll and

hydrostatically supported rotating shell. Main downside of the traditional deflection compensated roll is high energy consumption. High friction occurs in the hydrostatic system supporting the rotating shell. In this research, test device was built to perform conceptual investigation of suitability of aerostatic bearings to be applied in the deflection compensated rolls. Porous material aerostatic bearing was built in concave shape to interact with the shell of a roll. The bearing design was a combination of a bearing and a sealed chamber restricted with the bearing itself from the ambient. Air consumption, load and drive motor current were measured at various rotating speeds. The results of the research show the performance of the investigated bearing at various operating parameters, from which the point of highest performance can be determined. The results suggest that the porous material based aerostatic bearings as a technology is feasible to be applied in the deflection compensation systems. The validation of the feasibility of the concept of the aerostatic deflection compensation enables further investigations into optimizing the performance of the system for widespread utilisation.

1:10 p.m.	M. Wolf, M. Wittke, M. Torres Melgarejo, R. Theska (D-Ilmenau)

Scaling of a compliant mechanism for high-precision force measurement applications

This paper is dedicated to the mechanical structure of a force transducer for the measurement of very small forces in the nanonewton range with highest resolution and lowest measurement uncertainty. To achieve this, a low stiffness in one direction of motion, but high stiffness in all other directions of motion is required. Existing solutions that meet the requirements are not suitable because of their overall dimensions. This results in a need for miniaturization. For this purpose, the scaling behavior of an existing monolithic compliant mechanism is investigated and it is verified which joint contour provides an optimal stiffness ratio. It is shown that the corner-filleted contour in general has lower bending stiffnesses, but also lower cross stiffnesses compared to the semi-circular contour. A nonlinear scaling effect for the ratio of bending stiffness and cross stiffness in corner-filleted contour offers optimization potential. Based on a simplified rigid body model, additionally, the miniaturization of the mechanism is optimized. The stiffness in the desired direction of motion is reduced by about 85% compared to a semi-circular contour. The result is promising for the further development of a miniaturized force transducer. The findings of this work contribute to the advancement of the measurement of low forces and offer new perspectives for future research in miniaturized force sensors.

2:10 p.m. – 2:30 p.m. Coffee break and visits of expositions

3:15 p.m. Start excursion to Erfurt

Topic 2

Industry 4.0 and digitalisation in mechanical engineering

Session 2.1 | Production technology, machinery, digitalisation – State of the art and perspectives
Session 2.2 | Image processing based process and quality control
Session 2.3 | Plastics technology – Interfaces in materials, processing and manufacturing

Session 2.1 Production technology, machinery, digitalisation – State of the art and perspectives

Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 211/212
Chairman: J.P. Bergmann (D-Ilmenau)

10:20 - 10:40 a.m. Coffee break and visits of expositions	
10:40 a.m.	M. Reimche, J.P. Bergmann (D-Ilmenau)

Systematic literature research on method of order-related process subcontracting used by ETO – manufacturers

The special machinery manufacturing industry is one of the most important German innovation drivers and, as part of the German mechanical engineering industry, one of the most significant economic factors. The special machinery manufacturing industry is assigned to the ETO – concept and its orders represent a combination of a completely new development of individual components and the use of already developed or standard components. The ratio of existing components to developed or standard components has a significant influence on the complexity of the planning processes in terms of the expected workload of the resources and potential need for additional capacity. The main contribution of this paper is to use a systematic literature review to fully review the body of knowledge on methods for extending manufacturing capacity by order-related process subcontracting and assess their suitability for special machinery manufacturers. The objective was to identify the relevant publications from the last 5 years and to present the trends in research of the last years. Papers identified in the database Scopus were inspected according to the requirements of an ETO concept and the relevant papers were selected. The paper provides a detailed overview of the most relevant research results in the field of order-related process subcontracting.

11:00 a.m.	K. Sturm, S. Husung (D-Ilmenau), C. Wünsche (D-Deggendorf)

Error classification as a basis for automating the Automotive Conformity of Production process

In the automotive industry, the complexity of ensuring production conformity has increased significantly. Reasons for this are a growing number of vehicle variants in combination with increasing regulatory requirements in import markets. Violations of the "Conformity of Production" (CoP) can result in drastic penalties. This is contrasted by a partially random and manual inspection process that is currently not sufficiently automated and digitalized. According to the BMW Group CoP expert workshop there is not enough error analysis and classification in the current situation to comprehensively perform automated inspections. To gain more insight into this manual inspection process, a comprehensive error analysis and classification must first take place to derive measures. Based on the requirements

for the CoP process and the findings from the state of the art, the objective of this contribution is to analyze the status quo regarding error frequencies and to derive possible measures from the findings.

11:20 a.m.	A. Jevtic (RS-Belgrade), K. Petzold (D-Ilmenau)

Digital twins: Definition, application options in the product lifecycle and marketing

Germany is in the digital transformation process of the economy and society. Digital transformation influences not only production and marketing, but also the consumption and use of goods. The development and use of digital twins accelerate the digital transformation process and increase the competitiveness of the German economy. So far, the focus of research has been on the use of digital twins in the production of industrial goods. This article analyzes the use of digital twins in consumer goods marketing. For this purpose, the concept of digital twins is explained, and its use is presented over the entire life cycle of durable consumer goods. Subsequently, the possibilities of use of the digital twin in marketing will be presented and an outlook on further research fields will be given.

Elevator pitches and presentations 2.1 Production technology, machinery, digitalisation –State of the art and perspectives

Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 211/212
Chairman: J.P. Bergmann (D-Ilmenau)

	Elevator pitches Session 2.1
1:30 p.m.	P.-Y. Chen T-H. Hsieh, T-Hsien Hsieh, W.-Y. Jywe (CN-Taiwan)

Application of CNC machine tool and robot arm performance data acquisition and monitoring technology

The purpose of CNC machine tool information integration technology is to increase the digitization of machine processing information, the visualization of equipment dynamic state and the processing state of monitoring machine. Therefore, this study has carried out the monitoring and data acquisition for several major CNC machine tool. Through ethernet transmission mode, it can achieve many functions, such as monitoring machine operation, obtaining alert information and tool compensation. The internal data of the CNC controller is transmitted to meet the monitoring requirements, and the functions obtained in the future include machine information monitoring, NC program download, alarm message, tool compensation, pitch correction, etc. When the machine during the processing of abnormal alarm, will record CNC abnormal information, and then improve. ABB, Brother, Delta, DMG Mori, Fagor, Fanuc, Heidenhain, Kuga, LNC, Mitsubishi, Mazak, Siemens, Syntec, Toshiba, UR, Yaskawa's numerical control processor or robotic arm. In order to confirm whether the intermediate-layer function library currently encapsulated is correct, the encapsulation is imported into OPC UA Server and the test network environment is set up, the CNC machine tool and robot arm performance data acquisition and monitoring layout as shown in Figure 1. According to this network architecture, the portable device is used as the client of OPC UA, and the data and status of the arm are monitored at the remote end.

1:35 p.m.	J. Reimann, M. Rohe, A. Rauch, J. Hildebrand, J. P. Bergmann (D-Ilmenau)

Directed Energy Deposition-Arc (DED-Arc) and numerical welding simulation as a method to determine the homogeneity

This research presents a hybrid approach to for the prediction of the homogeneity of mechanical properties in 3D metal parts manufactured using directed energy deposition-arc (DED-Arc). DED-Arc is an additive manufacturing process which can offer a cost-effective way to manufacture 3D metal parts, due to high deposition rate of up to 8 kg/h. Regression equations developed in a previous study were

used to predict the mechanical properties of a wall structure using only the cooling time t8/5 calculated in a numerical welding simulation. The new approach in this research paper contains the prediction of the homogeneity of the mechanical properties, especially hardness, in 3D metal parts, which can vary due to localized changes in t8/5 cooling time provoked by specific geometrical features or general changes in dimensions. In this study a method for the calculation of the hardness distribution on additively manufactured parts was developed and shown.

1:40 p.m.	M. Rohe, J. Hildebrand, J.P. Bergmann (D-Ilmenau)

Investigation of a quantified sound probe for stud weld quality measurement with numerical simulation data and real-world welds

Drawn arc stud welding with ceramic ferrules is a widely used joining process for joining sheet metal to studs, which can be threaded or sheared. During the welding process, various irregularities can occur which adversely affect the resulting mechanical properties. Arc blowing is one of the most common process defects. Arc blowing can result in an asymmetric weld bead which can increase the failure rate of the stud. An approach to stud testing is given in DIN ISO EN 14555. A sound probe carried out by an experienced welder provides qualitative information about the weld bead. The sound probe causes the stud to vibrate at its natural frequencies. If the eigenfrequencies can be calculated for each weld bead shape, the sound probe can be quantified. To this end, a new simulation approach is presented which allows the rapid calculation of the eigenfrequencies of the stud with different weld bead shapes. A data set is also generated and analyzed.

1:45 p.m.	B. Neitzel (D-Ilmenau), F. Puch (D-Rudolstadt)

Demonstrations- und Transfernetzwerk KI in der Produktion (ProKI-Ilmenau) – Schwerpunkt: Fügen

Durch fortschreitende Digitalisierung entstehen neue Möglichkeiten zur Implementierung von datengetriebenen Algorithmen aus dem Bereich der künstlichen Intelligenz (KI). Ein großes Hemmnis vor dem Einsatz von KI-Methoden stellen derzeit vor allem fehlende interne Kompetenzen und Fachkräfte dar. Hier müssen Unternehmen umfassend und vielseitig, wie es durch die Initiative ProKI-Netz erfolgen soll, sensibilisiert und informiert werden. Insbesondere mittelständischen Unternehmen bietet die Digitalisierung chancenreiche Anwendungsfelder intelligenter Fertigungsverfahren. Am Beispiel des Fertigungsverfahrens Fügen, ergibt sich ein enormes Potenzial für die Anwendung von KI. Ziel von ProKI-Ilmenau ist die Etablierung von KI-Technologien mit Schwerpunkt Fügen innerhalb kleiner

und mittelständischer Unternehmen. An der TU Ilmenau sind die Fachgebiete Fertigungstechnik, Kunststofftechnik, Qualitätssicherung und industrielle Bildverarbeitung vertreten, die auf langjährige Erfahrungen und erfolgreich durchgeführte Projekte auf dem Gebiet Fügen und Anwendung von KI zurückblicken und einen Beitrag zum Zentrum leisten. Das Fachgebiet Data-intensive Systems and Visualization Group kann anwender- und fertigungsprozessbezogenen KI-Methoden und Modelle erstellen. Der arbeitswissenschaftliche Schwerpunkt wird im Zentrum durch das Fachgebiet Innovationsmanagement bearbeitet.

Presentations
Session 2.1

1:50 p.m.	A. Farahani, P. Atoofi, J. Votay, F. Hamker (D-Chemnitz)

Implicit Neural Representations for Deep Drawing and Joining Experiments

A deep understanding of metal deformation processes is essential for producing complex geometries in many industrial applications. Although simulations using Finite Element Methods (FEM) have helped in steering toward that goal, they are particularly time-consuming for large 3D meshes. Searching for the process parameters that lead to the desired shape of a metal part can become extremely expensive in terms of man-hours and computational resources. We investigated how machine learning models, especially deep neural networks, can help in speeding up the design process of deep drawing and joining processes by allowing a fast interpolation of FEM simulations from minutes or hours to seconds. In this study, inspired by implicit representations of 3D objects using neural networks, an implicit approach is used to predict local properties such as the thickness of the metal sheet, its thinning, and plastic strain, using solely the process parameters defining the experiment. We observe that the low number of trainable parameters of the predicting model ensures a generalization to unseen process parameters and ultimately allows for a reliable fast inspection of the processes.

2:10 p.m.	M. Sennewald, M. Hasieber, K. Szallies, J.P. Bergmann (D-Ilmenau)

Influence of microstructure and microgeometry of the probe on friction stir welding of AA 6060 T66

Increasing demands on joining technology in terms of lightweight and component complexity require the further development of welding processes. Friction stir welding is a promising alternative to conventional fusion welding. The central element is a tool consisting of a shoulder and a probe, which generates a heat input through rotation and pressure. However, FSW is subject to process-specific challenges, including high forces and tribological stresses. As the welding progresses, the tribochemical stresses cause the tool shape to change. The results are

premature tool failures. While previous investigations have focused on wear resistance by selecting a coating system and tool materials, the aim of this study is to adapt the probe by changing the microgeometry and microstructure. The present work investigates the influence and shows the extent to which tool wear and weld seam quality can be influenced. By analogy with machining, probes were prepared by drag finishing and the effect on geometry and wear will be demonstrated. A feasibility study will be carried out on the thread rolling of probes. This will show whether production by rolling is feasible and how the surface finish differs from that of the conventional ones. The investigations were carried out using a force-controlled robotic setup to weld 5 mm thick AA 6060 T66 sheets. A dynamometer was used to measure the forces. The weld seam properties were determined by visual and metallographic inspection and tensile tests.

2:30 p.m.	K. Szallies, J. Hüser, O. Piper, J.P. Bergmann (D-Ilmenau), B. Stoll (D-Erfurt)

An experimental study of interface formation in single-sided resistance spot-welded copper-aluminum joints

Due to the growing market for electrical applications copper can be substituted by aluminum, for cost reduction. Furthermore, the density of aluminum is less than copper, which can reduce weight. It is impossible to substitute copper with aluminum as electrical connector, due to its electrical properties. Therefore, a compromise was found by using both materials which created requirements for developing welding techniques for aluminum-copper dissimilar joints. In order to keep contact resistance low, welding processes play significant role. However, fusion welding of copper-aluminum joints causes the formation of a brittle and hard intermetallic phase, which affects the electrical properties. Furthermore, fusion welding of aluminum, is likely followed by porosity which can reduce the mechanical properties.

Resistance spot welding is the most common joining process in automotive applications. It is characterized by high reproducibility and short welding times. Limitations for conventional resistance welding arise regarding to materials with high electrical and thermal conductivity. Therefore, resistance welding of copper-aluminum dissimilar joints is a challenging task. To avoid these, a single-sided resistance spot welding was developed.

An analytic characterization of the welding interface between copper and aluminum using single-sided resistance spot welding is shown. The melt behavior, the diffusion zone and porosity of the aluminum as a function of heat is analyzed.

2:50 – 3:10 p.m. Coffee break and visits of expositions

3:10 p.m.	C. Diegel, L. Schmidt, K. Schricker, J. Löser, J. P. Bergmann (D-Ilmenau), F. Zaiß (D-Stuttgart)

Full penetration laser beam welding of high-alloyed steels using a concentric intensity distribution for spatter reduction

Modern solid-state lasers provide an increasing beam power, which enable high welding speeds. However, high welding speeds result in seam imperfections and the formation of spatters significantly reduces the seam quality due to material losses. The use of coaxial intensity distributions, consisting of core and ring intensities, shows a high potential regarding minimization of spatter formation due to its effect on melt and metal vapor flow. In this investigation, full penetration welds were performed to gain a fundamental understanding of spatter formation based on the systematic examination of top hat, core and ring intensities. Keyhole and melt pool behaviour were observed parallelly on the specimen top and bottom side by high-speed imaging. A significantly reduced spatter formation was determined by adjusting the intensity distribution, which was associated by a manipulated keyhole and weld pool size. Less spatters detached on the bottom side due to a reduced metal vapor flow.

3:30 p.m.	N. Humann, K. Schricker, J.P. Bergmann (D-Ilmenau)

Effect of shielding gas flow on weld seam surface in remote laser beam welding using a modular flat jet nozzle

Shielding gases in laser welding are of particular interest for materials interacting with ambient oxygen during welding. These materials are often processed by remote laser welding, where short welds (e.g., 40mm seam length) are commonly used. Such setups prevent gas nozzles from being carried along with the processing head due to the scanner application and require fixture-integrated nozzles to supply shielding gas locally.

This paper presents a systematic study of argon flow in interaction with the laser welding processes. A modular flat jet nozzle allowed the adjustment of Reynolds numbers (200-2400), flow section (25-250 mm^2), and duct lengths (25- 250 mm). A description of the flow field as a function of these parameters is presented and the effect of flow characteristics (i.e., turbulence intensity, flow velocity) on resulting welds (high-alloy steel AISI 304/X5CrNi18-10/1.4301) and tarnish colors are described.

3:50 p.m.	L. Schmidt, K. Schricker, J. P. Bergmann, S. Gourishetti, T. Krüger, A. Kátai (D-Ilmenau), S. Kodera, F. Römer, D. Böttger (D-Saarbrücken)

Detection of welding defects by acoustic process monitoring in laser beam welding

The detection of welding defects (e.g., spatter formation or lack of fusion) is a key parameter in industrial production regarding quality assurance and process control. Due to the high processing speeds in laser beam welding, fast measuring systems are required. In this area, existing solutions are limited by beam diameter, welding depth or sample size. However, an acoustic process monitoring based on structure-borne acoustic emission and air-borne acoustic emission shows advantages regarding high sampling rates, event-driven analysis of frequency bands and sensor integration (e.g., fixture-integrated).

In this paper, laser beam welding of high-alloy steel AISI 304 (X5CrNi18-10/1.4301) was carried out under the variation of welding joint (bead-on-plate weld, butt joint), process parameters (welding speed, beam diameter and focal position) and sheet thickness to provide data by means of structure-borne acoustic emission and air-borne acoustic emission. The data analysis is based on conventionally methods (e.g., filtering, autocorrelation, spectrograms) as well as machine learning methods (convolutional neural nets) and showed promising results with respect to the detection of welding defects. The results contribute to increase the understanding between weld defect formation and correlating acoustic emissions and thus provide a fundamental insight into an acoustic process monitoring.

End of session

Session 2.2 + Elevator pitches
Image processing based process and quality control

Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 201
Chairman: G. Notni (D-Ilmenau)

1:30 p.m.	R. Ramm. M. Preißler, C. Bräuer-Burchardt, S. Heist, P. Kühmstedt (D-Jena), G. Notni (D-Ilmenau)

Mobile 3D Sensor for Documenting Maintenance Processes of Large Complex Structures

With the new handheld goSCOUT3D sensor system, the entire surface of complex industrial machinery spanning several meters can be captured three-dimensionally within a matter of minutes. In addition, a comprehensive photo collection is registered and precisely assigned to the corresponding 3D object points in one hybrid 2D/3D model. At the basis of the robust 3D digitization are the measuring principles of photogrammetric reconstruction using a high-resolution color camera and simultaneous localization and imaging using a tracking unit. Following image acquisition, the process leading to generation of the complete hybrid model is fully automated. Under continuous movement of the sensor head, up to six images per second and a total of up to several thousand images can be recorded. Those images are then aligned in 3D space and used to reconstruct the 3D model. Results regarding accuracy measurements are presented as well as application examples of digitized technical machinery under maintenance and inspection.

1:50 p.m.	D. Vehar, R. Nestler, K.-H. Franke (D-Ilmenau)

Capturing 3D textured inner pipe surfaces for sewer inspection

Inspection robots equipped with TV camera technology are commonly used to detect defects in sewer systems. Currently, these defects are predominantly identified by human assessors, a process that is not only time-consuming and costly but also susceptible to errors. Furthermore, existing systems primarily offer only information from 2D imaging for damage assessment, limiting the accurate identification of certain types of damage due to the absence of 3D information. Thus, the necessary solid quantification and characterisation of damage, which is needed to evaluate remediation measures and the associated costs, is limited from the sensory side.

In this paper, we introduce an innovative system designed for acquiring multimodal image data using a camera measuring head capable of capturing both color and 3D images with high accuracy and temporal availability based on the

single-shot principle. This sensor head, affixed to a carriage, continuously captures the sewer's inner wall during transit. The collected data serves as the basis for an AI-based automatic analysis of pipe damages as part of the further assessment and monitoring of sewers.
Moreover, this paper is focused on the fundamental considerations about the design of the multimodal measuring head and elaborates on some application-specific implementation details. These include data pre-processing, 3D reconstruction, registration of texture and depth images, as well as 2D-3D registration and 3D image fusion.

2:10 p.m.	D. Garten (D-Schmalkalden), K. Anding, G. Polte, G. Notni, G. Polte (D-Ilmenau), E. Linss (D-Weimar)

Intelligent Classification and Data Augmentation for High Accuracy AI Applications for Quality Assurance of Mineral Aggregates
In this work, a method for automatic analysis of natural aggregates using hyperspectral imaging and high-resolution RGB imaging combined with AI algorithms consisting of an intelligent deep-learning-based recognition routine in form of hybrid cascaded recognition routine, and a necessary demonstration setup are demonstrated. Mineral aggregates are an essential raw material for the production of concrete. Petrographic analysis represents an elementary quality assurance measure for the production of high quality concrete. Petrography is still a manual examination by specially trained experts, and the difficulty of the task lies in a large intra-class variability combined with low inter-class variability. In order to be able to increase the recognition performance, innovative new classification approaches have to be developed. As a solution, this paper presents an innovative cascaded deep-learning-based classification and uses a deep-learning-based data augmentation method to synthetically generate images to optimize the results.

Elevator pitches
Session 2.2

2:50 p.m.	R. Illmann, R. Fütterer, M. Rosenberger, G. Notni (D-Ilmenau)

Investigation into the implementation of a multimodal 3D measurement system for a forestry harvesting process
In the context of digitalization, monitoring and traceability are also becoming increasingly important in the forestry sector. An essential component of the most

efficient value creation is the recording of relevant characteristics right from the start. The optical and tactile recording of characteristics, such as diameter and volume, have been solved to a large extent in the harvesting of heavy timber, but differs significantly from that of small timber. This paper is about an investigation on the implementation of a multimodal 3D sensor system, which is used for the stable detection of biomass directly in the harvesting process of weak wood. System technical possibilities are shown how biomass can be determined directly during the harvesting process by means of multimodal 3D measurement technology. Considerations regarding possible measurement principles and methods result in two methods, which are discussed within this thesis regarding their advantages and disadvantages. The development stages are presented in detail up to the practical tests, which also includes the acquisition of empirical a priori information. Finally, data are determined by means of test scenarios, which prove the principle functionality and make the methods evaluable.

2:55 p.m.	M. Richter, R. M. Rosenberger, R. Illmann, G. Notni (D-Ilmenau), D. Buchanan (D-Suhl)

Suitability study for real-time depth map generation using the Stereomatcher in OpenCV and Python

OpenCV presents an extensive free program library for a wide variety of challenges in all areas of image processing. An extension of the application to the field of forestry was aimed at here in the context of a project to capture the elevation profile of forest roads by means of stereo imaging. For this purpose, an analysis of the methods contained in OpenCV for the successful generation of depth maps was carried out. The program sections comprised the reading of the image stream, the image correction on the basis of calibrations carried out in advance as well as the generation of the disparity maps by the stereo matchers. These are then converted back into depth maps and stored in suitable memory formats. The aim was to design an evaluation program which allows the processing within one second for 30 image pairs. The reduction in processing time was achieved by processing multiple image pairs simultaneously and using storage formats without compression. A total processing time of 0.8 s could be achieved by outsourcing the stereo matching to the graphics card. However, the tested method did not achieve the desired resolutions in depth as well as in the image plane. This was made possible by using semi-global matchers, which are up to 10 times slower but significantly more accurate, and which were therefore used for further investigations of the forest path profile.

End of Session

Session 2.3 Plastics technology - Interfaces in materials, processing and manufacturing

Time: Wednesday, 06.09.2023
Location: Humboldt building, Lecture hall (HU-HS)
Chairman: F. Puch (TU Ilmenau)

9:00 a.m.	D. Müller, F. Puch (D-Ilmenau)

Seperation of plastic metal composites using molten salts

Given the increasing importance of environmental concerns, recyclability of plastics is a key issue. Furthermore, the quality and purity of the recycled plastics is a major concern for the processor to establish products with high amounts of reused plastics. The separation of plastic metal composites is currently established exclusively via chip-generating shredding. In order to enhance the recycling process of plastic metal composites, a novel separation approach is needed and is the foundation of this research.

The float-sink separation is well known in the plastic waste industry for sorting out low density plastics from metal parts. In this study, molten salts are used as the liquid medium of the float-sink separation. The salts used are eutectic mixtures of potassium nitrate, sodium nitrate and sodium nitrite with low melting points of 145 °C. By using the molten salts near the melting points of the plastic metal composites, the metal parts separate without significant material loss or flake generation.

The dwell time required for a separation depends on the plastic used and varies between 180 s (PBT) and 300 s (PA6). Further investigations focused on material degradation due to the dwell time in the molten salts. The investigated mechanical properties for all samples showed no significant differences. The floating-sink separation for plastic-metal compounds is applicable to various plastics and component geometries. The salt used can be largely regenerated and reused.

9:20 a.m.	N. Krempl, C. Holzer, W. Friesenbichler, U. Kitschnick (AT-Loeben)

Upcycling of regenerates and injection moulding into high quality light weight components using a new technological approach

The recycling of fiber-reinforced thermoplastic composites presents a significant challenge, leading to high waste generation and limited reuse options. The LightCycle project aims to address this issue by developing an energy-efficient and circular method for upcycling glass fiber composite waste and recycling polypropylene (PP). This work focuses on analyzing the material properties of PP regenerates (rPP) from post-consumer waste in Austria, as well as the compounds derived from it and glass fiber-reinforced thermoplastic composites. The goal is to establish material expertise and determine acceptable quality ranges for the LightCycle

process. Thermal and rheological material data measurements to analyze the material input quality and the fluctuation range suggest a stable LightCycle process with a wide process window. Furthermore, the analyzis of first compounds with rPP and two different types of shredded glass fiber reinforced thermoplastic composites highlights the significant impact of the type of flake used on the compound's properties.

9:40 a.m.	S. Mohammadkarimi, B. Neitzel, F. Puch (D-Ilmenau)

Influence of the Recycling Process Parameters on CFRTP Waste Properties

Nowadays, the combination of continuous fibers and thermoplastic polymers as the matrix to continuous fiber-reinforced thermoplastics (CFRTP) is receiving increasing attention due to their potential advantages such as excellent weight-specific mechanical properties, short cycle times, storability, repeated meltability, good formability and the use of alternative joining processes enabling automated large volume manufacturing processes which allow various applications in different industries including transportation, construction among others. As the production rate of these materials increases, the amount of waste for disposal increases, for which recycling strategies need to be established to ensure the sustainability of CFRTP. Hence, these recycling strategies must be developed and evaluated economically and ecologically to close the loop and achieve a circular economy to process recycled fiber-reinforced pellets from CFRTP waste to valuable products e.g., by injection molding. This study presents a mechanical recycling approach from CFRTP waste to injection molded test specimens and evaluates the impact of the individual recycling steps along the recycling chain on the fiber length as the fiber length is detrimental to the resulting mechanical properties. First, the CFRTP waste processability is investigated and conditions for size reduction by cutting and shredding into feedstock for extrusion are defined. Second, fiber-reinforced pellets are produced by twin-screw...

10:00 a.m.	B. Hiller, M. Rennert, M. Nase (D-Hof)

Comparison of the properties of biogenic wine by-products stabilized biocomposites compounded with a miniaturized single-screw extruder and a co-rotating twin-screw extruder

Bioplastics research is hindered by high material prices and limited availability of biopolymers. For conventional compounding, even on lab-scale, large quantities of material are required. In this study, an alternative process for compounding biocomposites was evaluated to investigate the potential of wine-derived biogenic by-products as functional fillers. Formulations based on poly(3-hydroxy- butyrate-co-3-hydroxyvalerate) (PHBV) and wine grape pomace (WP) with filler contents up to 10 wt.-% were prepared. The materials were processed with a

modified miniaturized single-screw extruder (MSE) and compared to a lab-scale twin-screw extruder (TSE). Thermal and rheological properties of the materials were determined using GPC, MFR, DSC, TGA and OIT. The mixing quality of both extruders was evaluated by optical microscopy imaging. The results revealed that the MSE represents an efficient alternative for research purposes, but differences in the dominant degradation mechanisms during processing must be considered. Thermal analysis showed that WP successfully suppressed the thermo-oxidative degradation of PHBV.

10:20 - 10:40 a.m. Coffee break and visits of expositions

10:40 a.m.	A. Baumann, J. Hausmann (D-Kaiserslautern)

Effect of high energy radiation on technical polymers

Fiber reinforced polymers (FRP) offer excellent fatigue resistance in combination with low specific weight. However, in contrast to metals, microscopic damage is usually present right from the beginning of cyclic loading and calls for insights on initiation and propagation. As with other properties, the overall performance of a composite is determined by its constituents namely fiber, matrix and fiber-matrix interface. Especially, the matrix polymer is supposedly responsible for damage initiation. To study this, different methods for altering the matrix properties can be used. The presented research makes use of Co-60 irradiation to modify the polymer on a molecular level. Six potential candidate materials for FRP are investigated, two thermoplastics and four thermosets. After irradiating the neat polymer samples with (30, 100, 200 and 500 kGy) the properties are investigated by quasi-static tensile tests and fatigue experiments. The resulting fractures are inspected visually. The results for thermoplastic materials show deteriorating tensile properties, whereas some of the thermosetting resins improve. Despite this, it could also be shown that deterioration in monotonic loading does not necessarily deteriorate the fatigue properties. The fracture surfaces indicate yielding as possible cause. Finally, it was shown that irradiation is a promising modification method for the investigation of composites and possible also a method to improve the fatigue performance.

11:00 a.m.	J. Köllermeier, V. Schöppner (D-Paderborn)

Optimizing the Processing Performance of a Single Screw Extruder Using Live Simulations Based on Real Time Experimental Data

Computer based simulation and digital assistant systems for extrusion processes are more in focus than ever before in the context of advancing digitalization. Although extrusion lines are well equipped with modern data interfaces including

graphical visualization and data analysis systems, it is not possible to give automated recommendations to react to changes of the operation conditions regarding process parameters or material conditions simultaneously. As a consequence, the machine operator is responsible for the product quality on his own.
This article aims to present a simulation system with an environment that enables live simulation of the process behavior of a single screw extruder based on real time experimental data. The simulated target variables such as pressure, temperature, throughput and melting behavior are visualized to the machine operator within an assistant system in a graphical form. The results can directly be assessed and furthermore, recommendations for process improvement can be carried out if the process behavior has to be optimized.In a first step, current process parameters such as pressure and screw speed are read repetitively from the extrusion control. Next, this data is used to simulate the process behavior in real time and afterwards, the results are sent to the assistant system. Finally, the results are visualized to the machine operator and based on the simulation results and expert know how potential for optimization can be generated.

11:20 a.m.	D. Trienens, V. Schöppner (D-Paderborn)

Investigation regarding the correlation of the relative influences during the extrusion process of cast films on the resulting melt quality
One key competence in plastics processing is extrusion on single-screw machines. In terms of volume, the extrusion process is the most relevant processing method for plastic granulates. One of the main goals of the plastics industry is to achieve consistent melt and product quality with increasing mass throughput in order to meet the constantly growing economic requirements. A specific machine design is particularly important for the efficiency of the extruder. The simulation tools currently available are not yet able to predict the expected product quality with sufficient accuracy. Suitable criteria are selected to adequately describe the melt quality. Extensive investigations form the data basis for the evaluation of the melt quality, on the basis of which the cause-effect relationships are revealed.

11:40 a.m.	A. Krombholz, A. Goldstein (D-Halle)

Development of a SmartSensor for the collection of process data in the material development of polymers using the example of an intelligent load cell
As part of the research project "SmartSensor 4.0", the Fraunhofer IMWS Halle and the company studio.201 Software GmbH from Magdeburg have developed a smart load cell unit as a use case for a smart sensor system. A sensor unit comprises multiple sensor channels. In addition to the force, environmental variables, such as temperature and humidity, and state variables like acceleration, can be

measured and transmitted wirelessly (via IoT) to a data server with a time series database. The system allows connection of multiple sensor units to this data storage. Selected data can be processed according to the desired application and made available for other services through a web interface. The continuous data acquisition in the three operating states test (online), movement and storage (offline in each case) ensures continuous monitoring for overloads or exceeded limits, enabling event-related notifications.
A rights management system, also designed as part of the project, provides control over the channel and function rights. A prototype, already constructed during the project, can be connected to a testing machine operated at the Fraunhofer IMWS. The concept for a smart sensor developed in the project can be applied to other industrial or research and development fields.

12:00 noon – 1:30 p.m. Lunch and visits of expositions

Topic 3

Mechatronics, biomechatronics and mechanism technology

Session 3.1 | Mechatronics – integrated actuators
Session 3.2 | Biomechatronics
Session 3.3 | Mechanism technology

Session: 3.1 Mechatronics
Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 210
Chairman: Th. Sattel (D-Ilmenau)

10:20 - 10:40 a.m. Coffee break and visits of expositions	
10:40 a.m.	M. Mauch, B. Gundelsweiler (D-Stuttgart)

Optimization of the actuation behavior of a hybrid electromagnetic switching/holding solenoid

Despite their long existence and diverse use electromagnets are indispensable and of paramount importance in many areas of technology like critical switching and positioning tasks in relay and valve technology. Due to increased requirements and technological progress, electromagnets offer further development potential. For example, conditions are placed on an adjustable force-air gap characteristic of the moving armature and, at the same time, low-noise operation and energy conservation are demanded. During the optimization of the mechanical subsystem, various elements, including a return spring for the plunger and a spacer with an integrated damping function, were integrated into the actuator. This provided for better and more reliable operation of the solenoid. Considering the electrical subsystem, a detection scheme was developed via a simulative approach consisting of an FEA simulation and derived co-simulation to determine the switching state based on monitoring inherent sensory properties of the solenoid. The inherent sensory properties of the electromagnet can thus be used for further investigations with regard to predictive maintenance and condition monitoring. With the detection of the switching state, the first step in this direction has been demonstrated. Further investigations will continue to explore the potential of hybrid electromagnetic switching/holding solenoids developed at IKFF and identify suitable fields of application.

11:00 a.m.	M. Hutter, B. Gundelsweiler, D. Holder, T. Maier (D-Stuttgart)

Multi-stable setups combining magnetic shape memory alloy with reluctance counter forces

Systems with the ability to hold a given position without consumption of energy, i.e. multi-stability, can be employed in a variety of applications. Apart from the most commonly friction-based systems, smart materials are an option to create multistability. Here, the ability to create a multistable system from magnetic shape memory alloy (MSM) in a magnetic field, combined with a reluctance counterforce is discussed. For the approach the necessary design process is described, as well as the experimental characterization of a demonstrator system. With the multistable range of the stroke at 0.82 mm and an average resistance to disturbance of ±10 N, two key parameters of the multistable properties are determined.

As an outlook, potential applications in the design of adaptable interfaces is discussed.

11:20 a.m.	L. Mettenleiter (D-Oberkochen)

Multivariable stability analysis of position-controlled payloads to support shrink in Semiconductor Manufacturing

This paper addresses the challenge of small structures in the semiconductor industry and the need for high performance mechatronic systems, especially wafer scanners, in lithography processes. The focus is on the development of advanced methods for modeling and analysis of control systems. The paper discusses the limitations of classical stability analysis methods and introduces the use of multivariable input-output (MIMO) methods to meet the requirements. Tailored MIMO analysis methods, including the Individual Channel Analysis and Design (ICAD) method and the classical Nyquist stability analysis, are presented and their application in the analysis of multivariable control systems is explained. A coupling ratio parameter derived from the ICAD method for quantifying the coupling of multivariable systems is presented. An iterative design process for optimizing system parameters to achieve high performance is described. A model of a mechanical payload is used to compare the methods in different system configurations. Finally, the paper highlights the importance of using advanced methods for designing high performance mechatronic systems in the context of semiconductor manufacturing.

12:00 noon – 1:30 p.m. Lunch and visits of expositions
12:00 noon – 1:30 p.m. Poster session

Session 3.1 Mechatronics

Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 210
Chairman: Th. Sattel (D-Ilmenau)

1:30 p.m.	F. Büchner, L. Jestädt, V. Ivanov, T. Bachmann (D-Ilmenau)

Self-adapting motion cueing algorithm based on a kinematics reference model

Due to a number of advantages over traditional development methods, the importance of dynamic driving simulators in automotive research and development has grown continuously in recent years. Motion simulation via motion cueing algorithms contributes significantly to the driving experience and provides the driver with valuable information about the current driving dynamics. The adaptation and tuning process of these algorithms can be difficult and time-consuming tasks. It needs to be repeated after changes to the vehicle or driving scenario. This paper discusses and presents an adaptive or rather self-adapting motion cueing algorithm (MCA) concept. The approach is based on the integration of a kinematic reference model to dynamically and adaptively adjust the motion behavior dynamically and adaptively. This concept allows to reduce the parameter tuning effort drastically in long term, since the algorithm can adapt itself to different conditions such as vehicle type, driving situation, or driver behavior. In the following, the proposed algorithm structure is explained and illustrated. The advantages of the proposed MCA are demonstrated by an experimental comparison with a classical algorithm. Thereby it is shown how a self-adaptation of the algorithm can proceed and how to avoid violation of workspace boundaries.

1:50 p.m.	F. Büchner, B. Rieger, B. Purschke, V. Ivanov, T. Bachmann (D-Ilmenau)

Extending teleoperated driving using a shared x-in-the-loop environment

The strong progress in modern vehicle system technology requires new methodological approaches for the development and validation of new vehicle systems. In particular, due to increasing automation, classical development methods and testing scenarios need to be evolved. Consequently, the publication focuses on an extension of teleoperated driving by the X-in-the-loop (XIL) approach. Within this framework, the classical concept based on VPN-LTE networking is analyzed and discussed at first. With this implementation, the remote control of a real vehicle is presented based on the use of a dynamic driving simulator. Especially for the development and validation of such concepts, an extension with the XIL methodology can improve this process. For this reason, the architecture of teleoperated driving is subsequently extended by networking with additional system components. The feasibility, the functionalities as well as the challenges that arise with

such an extension based on the XIL methodology are shown. Within the scope of this study, the achieved transmission times for the control variables and for the video data stream are demonstrated. Based on different driving maneuvers, the achievable repeatability is discussed.	
2:10 p.m.	E. Carrillo Li (PE-Lima)
Hybrid Fuzzy Neural Network – Genetic Algorithm applied to the control of Magnetorheological and Smart Material Vehicle Active Suspensions The document content a brief introduction of smart materials oriented to the magnetorheologic materials such Elastomers and Fluids. The characteristics of those materials are short explained and a model of devices in which they are applied are modeled. A vehicle model is presented with a semiactive suspension systems which includes the modeled devices. The model has been optimized by genetic algorithm in order to find the optimal parameter, also a Fuzzy-Neural control for the suspension system is developed. The document includes a simulation of the dynamic vehicle behavior and a comparison between a vehicle with a passive suspension system is made.	
Elevator pitch	
2:30 p.m.	G. Gárdonyi, S. Zoletnik, T. Szabolics, E. Walcz (H-Budapest)
Control System for Shattered Pellet Injection Experiments	
2:50 – 3:10 p.m. Coffee break and visits of expositions	
End of session	

Session: 3.2 Biomechatronics
Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 204
Chairman: H. Witte (D-Ilmenau)

10:40 a.m.	R. L. Stoeterau, V. F. Soares (BR-São Paulo)

Flow and Hemocompatibility Study of Straight-Bladed Impeller Ventricular Assist Devices

Ventricular Assist Devices are continuous flow pumps that act as cardiac orthoses. The evaluation of the compatibility of such devices with blood involves, among other aspects, the study of thrombogenicity, hemolysis, and platelet activation. Computational Fluid Dynamics simulation is one of the tools used in this kind of evaluation. Thus, this work used Computational Fluid Dynamics simulations in the analysis of three Ventricular Assist Devices models under development, generating their velocity and pressure contours, their characteristic curves, and the distribution of shear stresses in their walls. A blood model has also been developed in order to estimate the damage inflicted on the blood by the devices. Steady-state simulations were performed, applying the Multiple Reference Frame method. The numerical blood modeling used the Lagrangean approach, with a discrete phase. The estimation of the damage on the blood was based on the relationship between the residence time of the discrete phase and the scalar shear stress. The prototype of one of the models was bench tested to validate the simulations. The simulation results relate the geometry of the models to the characteristics and magnitudes of the recirculation and stagnation regions and to the distribution of shear stresses. The energy performance of each pump and the blood damage index were used as comparison metrics between the devices.

11:00 a.m.	C. Rincon, J. Alencastre (PE-Lima)

Analytic modelling of a dynamic vibration absorber for Parkinson disease

Parkinson is the most common neurodegenerative disease. It is characterized by the presence of involuntary tremor of human arms. Current treatments as pharma-cological and surgery can be invasive for patients due to secondary effects and also high costs are required. In this sense, non-invasives devices have been proposed in order to reduce the tremor amplitude without secondary effects. These devices require a model in order to analyze the dynamic behavior and calculate the opti-mum parameters. In this article, it is developed an analytical three-dimensional model of a dynamic vibration absorber placed on a human arm. Results show dy-namic vibration absorber is effective to reduce the tremor during voluntary motion. However, it is only effective while tremor frequencies are within a narrow range around the tuned frequency used for calculation of absorber parameters.

11:20 a.m.	K. Uhrhan, M. Jäger, H. Witte (D-Ilmenau)

Threshold based reduction of EMS stimulation artifacts in the electromyogram when stimulation intensity increases

To investigate muscular strain, it is possible to record an electromyogram (EMG) during electromyostimulation (EMS). However, stimulation artifacts make it difficult to examine evoked compound muscle action potentials (M-waves). The aim of this work was to algorithmically remove stimulation artifacts from the EMG signal when the stimulation intensity increases. For this purpose, EMG signals were recorded on four subjects who underwent a 30-second EMS of the right M. triceps surae. Afterwards we conducted offline signal processing to reduce stimulation artifacts. We implemented a two-stage threshold algorithm, adapted from O'Keeffe et al. (2001), to remove signal segments passing the thresholds in a defined sequence. Here, the thresholds in the first iteration are two constants, while the algorithm uses linearly or exponentially increasing thresholds in the second iteration. After empirically adjusting the threshold parameters, the stimulation artifacts were successfully reduced. This allows further investigations of the M-waves with respect to muscular fatigue.

11:40 a.m.	E. Andrada (D-Jena)

Capturing the Neuromechanics of Rat Locomotion for Building Synthetic Neuronal Systems

The understanding of the organization and function of spinal motor systems that lead to stable gaits is one mayor topic for understanding animal locomotion. In our international project Neuronex we combine behavioral, neurophysiological, computational, and robotic experiments to understand how mechanical scale and task demands determine the function of low-level control centers in the spinal cord and their interactions with high level control centers in the brainstem in small mammals.

The development of synthetic neuronal systems, which is one of the main goals of our project, will help to link all these scientific fields. Sophisticated synthetic neuronal systems need to mimic the interactions between spine and higher locomotor centers. Small mammals like the rat are a good animal model to infer such interactions during posture and quadrupedal locomotion. Like for any dynamical system, their control strategies can be characterized by analyzing how they respond to external perturbations. To measure them, we designed a novel three-degrees of freedom platform, called “the shaker”. The shaker can generate single or combined horizontal, vertical, and tilting perturbations. In the conference, we will inform

about the results of the world-wide first studies on rat actively perturbed locomotion. During perturbations, we recorded three-dimensional bones kinematics, single leg ground reaction forces, and electromyography of selected muscles of the hind limbs.
12:00 noon – 1:30 p.m. Lunch and visits of expositions **12:00 noon – 1:30 p.m. Poster session**

Session 3.2 Biomechatronics

Time: Tuesday, 05.09.2023

Location: Humboldt building, Lecture room 204

Chairmen: R.L. Stoeterau (BR-São Paulo) / E. Andrada (D-Jena)

1:30 p.m.	T. Helbig, H. Witte (D-Ilmenau)

Methods to investigate the acoustic properties of the outer ear canal

The ear canal and its huge geometric variance in cross section as well as its path have a strong influence on the complex sound field in the outer ear canal and the sound pressure level (SPL) resulting at the eardrum. One way to describe this influence is the outer ear transfer function (OETF) as a part of the head-related transfer function (HRTF). In a preliminary study the OETF of fifteen test subjects was measured *in vivo* using an AFFINITY measuring system by DIATEC DIAGNOSTICS GMBH. This system was used to measure the difference in SPL between a measuring point in front of the eardrum and a measuring point in front of the ear. Results illustrate the strong influence of the general shape of the outer ear canal. However, generalized interpretations of the results are not appropriate because of uncertainties in the measuring method. To analyze and appraise isolated parameters a finite element (FE) model as well as an experimental setup were developed. SPL was analyzed in an imaginary plane close to the approximated natural eardrum position for various parameters. These results re-inforce the preliminary results. The general geometry of the outer ear canal seem to have the strongest influence on the SPL arising at the eardrum. Other parameters like the pose and shape of the eardrum seem negligibly in comparison.

Part of this work was funded by the „Berufsgenossenschaft Nahrungsmittel und Gastgewerbe (BGN).

1:50 p.m.	P. Jünemann, A. Schneider, J. Waßmuth (D-Bielefeld)

Comparative study of a bio-inspired sound source localization algorithm and a standard beamformer

This work presents a study that compares the angular accuracy of a binaural bio-inspired method with classical delay-and-sum beamforming using linear acoustic arrays with an increasing number of sensors. In addition, this study also focuses on the frequency band dependent angular accuracy of the bioinspired method, as previous work has optimized it only for localizing narrowband sound sources. Therefore, a comparison of the localization accuracy for narrowband and broadband excitatory sounds is presented. This enables conclusions about the potential to reduce resources in terms of sensor array spatial requirements and the number of sensors if a bioinspired system is used.

2:10 p.m.	Raman, S. Labisch, J.-H. Dirks (D-Bremen), H. Witte (D-Ilmenau)

Ultrastructure, biomechanics and biomimetic potential of starfish skeletons

Starfish posses an exceptional endoskeleton, formed by many intricate bone-like structures (ossicles) embedded in a collagenous matrix. These ossicles are connected by small muscles known as inter ossicular muscles (IOMs). Contraction of IOMs leads to a controlled deformation of the skeleton. Control of the matrix fibres also allows starfish to vary their body stiffness and to remain in the same posture for a prolonged period whilst using very little energy. These features make starfish skeletons an interesting biological model for bioinspired morphing structures. The ossicles show the presence of an intricate microstructure. To investigate if the morphology of this ultrastructure is correlated with biomechanical stresses, we performed FE simulations on 3D ossicle models based on X-Ray CT scans. We analyzed the porosity distribution within representative ossicles and across ossicles of different ontogenetic stages. To study the interaction of ossicles during locomotion, we then performed multibody simulations. Using 3D micro-CT data we designed a CAD model. In this model, forces corresponding to the muscle attachment sites were applied and the resulting motion of the ossicles was analysed. This data allowed us to discuss the structure-motion relationship of the ossicle network. Finally, we developed a prototype based on the structure of the starfish skeleton that can hold itself in any position without consuming any energy and allowing for a reversible change of shape.

2:30 p.m.	C. Schilling, S. Köhring, H. Witte (D-Ilmenau)

A contribution to forest monitoring, here the dendrometry

To know, whether a tree at a site is vital in the present and viable in the future is of growing relevance. One parameter that can provide information about the constitution of a tree is its increase in trunk perimeter. This contribution to the topic of forest monitoring, more precisely dendrometry, is motivated from this perspective. Based on market research on existing dendrometers and defined demands of users, a concept for a new dendrometer was developed in several stages, which was implemented and successfully tested as a demonstrator. The idea was to simplify an electronic measurement of tree trunk perimeter growth, and to make it accessible to a wider range of users. As a preliminary result, a graph of the trunk perimeter of a pine tree from values measured hourly over 15 months is presented and, among other things, two dents conspicuous therein are discussed. The documented material can serve as a template or inspiration for context-specific topics.

2:50 – 3:10 p.m. Coffee break and visits of expositions

3:10 p.m.	T. Helbig, J. David, S. Lutherdt, H. Witte (D-Ilmenau)

Measuring kinematic parameters of the human hand for application in human-machine-Interaction

The human hand with its opposable thumb is an essential tool to handle and manipulate all types of objects as well as to communicate. Knowledge and tracking of the kinematics can be beneficial for developing intuitive operating concepts for novel types of human-machine-interaction. To measure 14 of 15 angular values of a simplified hand model as well as five contact pressures at the fingertips and inertial data of the whole hand with a degree of freedom of 6 a wearable for the human hand called SenGlove was developed. All angles of all finger joints of the hand can be determined digitally and simultaneously. The root mean square error achieved for the joint angles is below 2.38° surpassing the human perception threshold. SenGlove is designed concerning a high adaptability and cost efficiency by applying (bio)mechatronic design principles and concepts and using only commercially available components. The textile support structure can be adapted to the hand size of the wearer as well as to the position of the sensors. The wearable can be equipped with sensors for any combination of fingers of the hand. Therefor SenGlove can be used as platform for general technical developments or scientific research. In this contribution, SenGlove is utilized to examine usability aspects of such wearables in human-machine-interaction. For that purpose an exemplary task scenario was defined and analyzed with tools and methods of ergonomic examination.

3:30 p.m.	M. Jäger, T. Helbig, H. Witte (D-Ilmenau)

Control for non-linear compliant actuation of an upper arm exoskeleton

Musculoskeletal diseases of the back and upper extremities are one of the main causes of sick leave in Europe. Exoskeletons are one possible approach to preventive measures. The Biomechatronics Group at Technische Universität Ilmenau is developing an antagonistically actuated exoskeleton with non-linear compliance to support flexion and extension of the elbow in repetitive tasks like in assembly. Here, we present a control strategy to achieve joint stiffness control while benefitting from the advantages of non-linear compliant actuation. We use a decentralized control approach, combining two PID controllers to control joint position and string force and thus, joint stiffness, in the antagonistically acting drive. We show limitations and benefits of this approach through simulation and measurement.

3:50 p.m.	L. Schaeffer, D. Herrmann, V. Böhm (D-Regensburg)

Theoretical considerations on a 2d compliant Tensegrity joint Structure in context of a Biomedical Application

In this paper, a two-dimensional compliant tensegrity joint was investigated for potential biomedical applications such as orthotics or exoskeletons. The structure consists of two compressed members connected by five compliant tensioned members. The concept is based on the tensegrity principle, which allows the realization of dynamic orthoses without conventional hinge joints. Another advantage is the adaptability to the individual needs of the patient through a suitable design of the structure and the careful selection of the characteristics of the elements. Using geometric nonlinear analysis, the mechanical behavior of the structure was investigated, focusing on mechanical compliance. The main objective was to determine the influence of the initial length and stiffness of the tensioned members and the influence of the magnitude of external forces on the overall stiffness of the movable member of the structure. The results highlight the significant impact of member parameters on the structure's stiffness and movability under varying load magnitudes. The research laid the foundation for future development of dynamic orthoses based on this structure.

4:10 p.m.	C. Hönemann, S. Lutherdt, H. Witte (D-Ilmenau)

Digital examination in bio-oriented courses at Technische Universität Ilmenau

By using evaexam online software package, new examination formats can be generated effectively and in an user-friendliness matter. F. e. existing questionnaires from paper & pencil version can be further used to generate online exams by drag & drop handling. In our article, we also show the possibilities offered by the integration of an additional subject-specific online learning software (Elsevier Complete Anatomy). This combination enables new learning, exercise and examination formats, which use should lead to an increase in students' competence.

In order to check the level of competence achieved, automated evaluable practice tests are to be developed and offered to students on an ongoing basis. Students can take these on an ongoing basis independently as well as at scheduled intervals. Specific tasks are set for the respective main topics, which had to be solved with the help of the Complete Anatomy learning software with the possibility of collecting bonus points for completing the course.

4:30 p.m.	J. Steinz, S. Lutherdt, H. Witte (D-Ilmenau)

Concept for the measurement of vital parameters during the use of an infrared cabin to investigate physiological effects and to individualize the sauna session

Infrared sauna bathing has positive effects on body and mind. Quantifying these effects helps to make sauna use more efficient and safer and to increase the user-observed wellness effects. Currently, there are no practical solutions for a comprehensive and user-friendly monitoring of the physical impact of sauna bathing. This paper focuses on the concept development to investigate which measurement setups are suitable to record and evaluate changes in vital parameters. Based on prioritized vital parameters and requirements a pre-selection of devices in form of wearables is made, which is going to be examined in detail for their suitability. An investigation with ten test persons is planned, in which the wearables' measurement accuracy and the user acceptance outside and inside the infrared cabin are quantified. The result is a concept for the test procedure and the evaluation of the wearables in order to integrate a suitable device into the overall system.

End of session

Session: 3.3 Mechanism technology
Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 012
Chairman: L. Zentner (D-Ilmenau)

10:20 - 10:40 a.m. Coffee break and visits of expositions	
10:40 a.m.	D. Herrmann, L. Schaeffer, V. Böhm (D-Regensburg), L. Zentner (D-Ilmenau)

Theoretical considerations on 3d tensegrity joints for the use in manipulation systems

This paper presents a comprehensive analysis of a three-dimensional compliant tensegrity joint structure, examining its actuation, kinematics, and response to external loads. The study investigates a baseline configuration and two asymmetric variants of the joint. The relationship between the shape parameter and the parameters of the tensioned segments is derived, enabling the mathematical description of cable lengths for joint actuation. Geometric nonlinear static finite element simulations are performed to analyze the joint's response under various load conditions. The results reveal the joint's range of motion, the effect of different stiffness configurations, and its deformation behavior under external forces. The study highlights the asymmetric nature of the joint and its potential for targeted motion restriction. These findings advance the general understanding of the behavior of the considered tensegrity joint and provide valuable insights for their design and application in soft robotic systems.

11:00 a.m.	E. A. Hermoza Llanos (D-Aachen), J. A. Rodriguez Hernandez PE-Lima), L. Zentner (D-Ilmenau)

Development of a novel synthesis method of a rigid-body four-bar linkage into a compliant mechanism

The four-bar linkage mechanism is widely used in various machinery applications. This study presents a synthesis method to transform a rigid-body four-bar mechanism into a compliant mechanism using four leaf-type hinges based on linear theory and Castigliano's Theorem. The objective is to determine the dimensions and configuration of a flexible four-bar mechanism that replicates the behavior of the initial rigid-body mechanism. The meeting point between the two mechanisms is the flexure hinge of the compliant mechanism, which is determined using the Pseudo-Rigid-Body model (PRBM). To validate the proposed method, a program based on non-linear theory is employed. The results confirm that the dimensional differences between the two are minimal, ranging from 0% to 0.13%. This study demonstrates the feasibility of synthesizing a Rigid-Body

Four-Bar Mechanism into a compliant mechanism using the PRBM, as long as the deformations are within the linear domain.

11:20 a.m.	D. Stojiljković, N. T. Pavlović (RS- Niš)

Design of the compound compliant scott-russel mechanism with non-conventional optimization of flexure hinges

Compliant mechanisms gain some or all their mobility from the relative flexibility of their joints rather than from rigid-body joints only. Compliant mechanisms can provide many benefits in the solution of design problems: they have less wear, weight, noise, and backlash than their rigid-body counterparts. However, nonlinearities introduced by the large deflection of elastic segments further complicate the analysis of compliant mechanisms. This paper considers the isosceles slider–crank mechanism and its compliant counterpart mechanism, being developed based on the rigid–body mechanism. The design of the compound compliant slider-crank mechanism with circular flexure hinges notch, consisting of two single compliant slider-crank mechanisms has been shown in this paper. The guiding accuracy and mobility of the newly designed compliant mechanism have been analyzed. Additionally, by using undercut notch flexure hinges, a new analysis is given, which aims to show another factor that has an impact on the operation of compliant mechanisms. This factor is represented by the position of joints and its influence is shown through improving the accuracy of the coupler point rectilinear path of the Scott-Russel mechanism. Hence, it will be described that the position of these flexure hinges and their geometry is a vital issue for performing an approximately rectilinear path. Therefore, several designs are investigated through the finite elements method (FEM) simulation.

12:00 noon – 1:30 p.m. Lunch and visits of expositions
12:00 noon – 1:30 p.m. Poster session

Session: 3.3 Mechanism technology
Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 012
Chair: L. Zentner (D-Ilmenau)

12:00 noon - 1:30 p.m. Foyer Humboldtbau | Poster Session	
13:30 a.m.	S. Rödiger (D-Weimar)

Weight reduction in lightweight structures of dynamically loaded systems by new energy dissipative elements
In order to reduce vibration amplitudes, joint damping is being investigated at the MFPA Weimar and Fraunhofer IWM. It is intended to replace damping, often done by a frequency shift of naturals frequencies via added masses, and thus contribute to lightweight construction. To characterise the energy dissipation ability of joints, fretting wear tests with various parameter settings have been performed. Friction in the joint creates a friction-force-hysteresis, the area of which reflects the energy dissipation. The larger the hysteresis area, the greater the energy dissipation. Based on the experimental observations, a new material model is formulated to capture energy dissipation starting form micro slipping up to macro-slip situations in joints. The constitutive law is defined in a finite element method (FEM) in intermediate elements between two friction bodies, where energy dissipation can be simulated for complex geometries. The numerical calculations are compared with validation experiments. Bolted joints are investigated as an application. The pressure distribution in the connection depends on the distance of the considered point to the bolt. According to distance, the constitutive law is variously implemented in the joint. Bolted joints exhibit both micro-slip (near the bolt shank) and macro-slip as relative motions, resulting in different friction states in the joint.

13:50 a.m.	S. Gutschmidt, S. Becker (NZ-Christchurch), I. Rangelow D-Ilmenau)

Underlying physics of thermal actuation in composite MEMS
Integrated micro- and nano-electromechanical sensor (M/NEMS) and actuator technology has become increasingly important to any applications using parallel processes, which clearly provide advantages in fields such as e.g. high-speed imaging technology and precision metrology of large substrates. Although microfabrication processes for integrated technology are well-established today, there remain several fundamental research questions regarding optimization of design parameters for an improved performance of sensors and actuators. In this work we investigate the underlying physics of a thermal actuator of a composite MEMS

structure for a selected range of design parameters, namely layer thicknesses, number of layers, as well as material properties. We derive and present a one-dimensional heat conduction model of a composite slab and investigate the heat transfer across three layers by solving the differential equation using Green's function. The work, although entirely theoretical here, finds direct meaning and implementation in our ongoing collaborative work on MEMS arrays for Atomic Force Microscopy (AFM).

End of session

Topic 4

Systems engineering

Session 4.1 | Components, systems and materials
Session 4.2 | Systems engineering for demand-oriented products
Session 4.3 | Metallic and hybrid materials and simulation

Session 4.1 Components, systems and materials

Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 201
Chairman: U. Kletzin (D-Ilmenau)

10:20 - 10:40 a.m. Coffee break and visits of expositions	
10:40 a.m.	C. Otto, V. Geinitz, U. Kletzin (D-Ilmenau)

FEM simulation of wire drawing

The paper deals with the finite element simulation of wire drawing processes with focus on unalloyed carbon steels. First, the developed simulation model is presented, which simulates the real wire drawing process. Based on the development of suitable material models as a basis for the simulation model, the forming processes were analyzed over several drawing stages for different drawing regimes. The simulation model is validated by comparing the simulation results with measured values. For the description of the forming behavior, the damage developments of the wire during the multi-stage forming are specifically analyzed. Subsequently, forming limits are derived by correlating the calculated damage with mechanical parameters of the wires. The validation of the damage models used is made possible by an FE parameter study, within which a targeted variation of the drawing die geometry takes place at a specific drawing stage. The paper is concluded by the verification of the results obtained theoretically by practical tests on a wire drawing machine using critical drawing die geometries. The derived correlations allow for the first time an optimization of wire drawing processes with regard to damage minimization and energy saving.

11:00 a.m.	J. Schleichert, U. Kletzin (D-Ilmenau)

Relaxation behavior of (cylindrical) helical compression Springs

This paper deals with the relaxation behavior of helical compression springs made of different types of spring steel wire. The starting point of the examinations marks the creep and relaxation behavior of similar preprocessed wires, prior to the cold forming, under torsional stress. The pre-treatment consists of two to three well-established levels of heat treatment, in part followed by a pre-torsioning of the wires as far as entering the plastic range – respective (cold-)presetting of the springs. In addition to the pretreatment process, the level of (torsional) stress and the surrounding temperature, which the wires and springs were exposed to during the creep and relaxation tests, have been varied as well. In this context the main influencing factors regarding creep deformations and relaxation losses are discussed and the particular findings contrasted, which allows for transfer factors to be deducted. The mathematical models, forming the evaluation basis of the experimental data, are based upon the NORTON-BAILEY

creep law and utilized to determine creep specific characteristics and identify material constants. Doing so enables the deviation of calculating instructions to estimate relaxation losses of helical compression springs based on numerous influencing factors. Applying those calculation methods facilitates the deduction of relaxation figures as well as recommendations regarding the manufacturing process in order to achieve springs with favorable relaxation behavior.

11:20 a.m.	M. Petrich, T. Weimann, J. Feld, C. Otto, S. Titze, O. Ziems, L. Thein, A. Sauer, U. Kletzin (D-Ilmenau)

Behavior of FRP-Sandwich Structures for Lightweight Composite Springs in Static and Cyclic Load Cases

Fiber-reinforced polymers (FRP) are established as high-tech materials for special purposes such as racing cars, planes or bicycles. Nowadays, they are increasingly used for functional parts and machine elements. For lightweight optimization, FRP sandwich structures can be used, which also appear to be suitable for spring applications. But material data availability is often limited for UD-specimen or specific load cases, which makes it difficult to use FRPs for technical springs. In order to reduce this gap and to facilitate the development of new applications, this paper deals with the basic static and cyclic behavior of FRP sandwich strips under torsional load. Therefore, manufacturing methods have been developed, to produce FRP strip specimens with GFRP and CFRP shells containing various core materials. An analytical model was used to describe the static behavior, which shows decent agreement with test results. Initial studies on fatigue characteristics of these strips were carried out as well as tests on associated volute springs. The results contribute to composite lightweight spring design and could extend the range of applications for composite springs in the future.

11:40 a.m.	D. Lavayen-Farfan, J. Yarasca-Huanacune, J. Rodríguez-Hernández (PE-Lima), J. Butenegro-García, M. López-Boada (ES-Madrid)

On the bending collapse behavior of rectangular hollow steel shapes of various thicknesses

Rectangular hollow steel shapes are widely used in numerous engineering areas due to their availability and price. In large vehicles, such as buses, these shapes also contribute to the overall crashworthiness of the vehicle, as they absorb most of the kinetic energy of an impact, and dissipate it as localized plastic deformation during a process known as bending collapse. Since a correct calculation of the crashworthiness of a structure is vital to ensure the safety of the occupants of a vehicle, special care must be taken to address the bending collapse behavior, as it is a major energy absorption mechanism. This research aims to investigate the

effects and influence of thickness of the hollow shape on the bending collapse characteristics, and thus on the crashworthiness of a vehicle. Furthermore, regulations regarding crashworthiness often require some sort of experimental validation of the zones that undergo bending collapse. However, since there is no standardized test for bending collapse, the results from two types of experimental setups are compared, to study the influence of the setup on the bending collapse behavior. The results provide a detailed understanding of the failure modes of these shapes under bending loads. Additionally, the research provides insights into the design and optimization of rectangular hollow steel shapes, which will be useful to engineers and designers in the selection of thicknesses that are most appropriate for specific applications.

12:00 noon – 1:30 p.m. Lunch and visits of expositions
12:00 noon – 1:30 p.m. Poster session

Session 4.2 Systems engineering for demand-oriented products

Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 202
Chairman: S. Husung (D-Ilmenau)

10:20 - 10:40 a.m. Coffee break and visits of expositions	
10:40 a.m.	M. Steck (D-Reutlingen), S. Husung (D-Ilmenau)

Methodical procedure for a surrogate model based fatigue calculation to support the design process of eBike drive units

In this paper, a method is developed to consider multiaxial load spectra and their variation in a computationally efficient local fatigue calculation procedure. This method is based on an FE data-based surrogate model and is intended to support the simulation-based product design process. To demonstrate their application and necessity, a case study on the design of eBike drive units is presented. For this purpose, the general requirements for the design of eBike drive units as well as the fundamentals of multiaxial fatigue analysis and surrogate modeling are outlined. In addition, a validation process of the surrogate model and its use for fatigue calculation is presented and discussed.

11:00 a.m.	D. Gerbet, K. Röbenack (D-Dresden)

On the Observability of Embedded Polynomial Dynamical Systems

Testing a system for observability is of great practical relevance in technical applications. For linear systems, this problem was solved decades ago. The observability of nonlinear systems can be formally defined, but the actual verification is extremely difficult. For the subclass of poynomial systems, the observability can be decided in a finite number of calculation steps. In this paper, we provide an observability test for embedded polynomial systems. The observability test uses methods of algebraic geometry.

11:20 a.m.	A. Albers, T. Hirschter, J. Fahl, P. Tröster, R. Simon (D-Karlsruhe)

Understanding the variation of physical elements and their impact on properties and functions: a case study on roll stabilization systems

This paper explores the variation in physical elements, functions, and properties of roll stabilization systems in automobiles over successive generations. Two key methodologies, Characteristics-Properties Modelling (CPM) / Property-Driven Development/Design (PDD) and the C&C²-Approach (Contact and Channel Approach), are utilized to analyze the attributes of the system elements and their functional correlations. Through detailed comparison of traditional roll stabilization subsystems and the active roll stabilization system, the research uncovers several correlations between variation types and system properties. The findings

show the importance of attribute variation for understanding complex mechatronic systems. The research results may guide future planning of new product generations and foster innovative solutions in the early phases of product development.

Elevator pitches
Session 4.2

11:40 a.m.	R. Watty (D-Ulm)

Buildup of competences for agile product design by means of student projects
The increasing complexity of technical solutions caused by constantly changing requirements and competitive situations, has led to the introduction of agile development processes in various domains in order to be able to react faster and more efficient to changes. This paper explores the integration of agile aspects into engineering education to prepare students for the corporate world. Two approaches, a single-stage and a two-stage approach, were implemented and evaluated in student projects at Technische Hochschule Ulm and Technische Universität Ilmenau. The findings reveal that both approaches effectively enhance students' competencies in agile product development. The observations highlight the value of iterative sprints, design thinking, peer learning, focused work, stakeholder involvement and the application of digital tools. Students exhibited increased confidence, independence, and creativity in their development projects. The integration of agile approaches in teaching methodologies proves beneficial in addressing the challenges posed by complex technical solutions and evolving requirements.

11:45 a.m.	T. Brix, S. Husung, S. Bücker (D-Ilmenau)

Sustainability strategies and their influence on the product development of machine tools and special machines
In the context of product development, the goal of developers is to design products based on a variety of stakeholder needs so that they sufficiently satisfy a wide range of required characteristics. The required properties relate to function, safety, manufacturability, cost, usability, etc. In recent years, sustainability has gained importance as an additional and now indispensable guiding principle in product development due to the rapidly growing global environmental, social and economic challenges. The focus of this paper is on sustainability, which takes into account resource consumption, environmental protection and ecology. The same applies to the circular economy as an essential component of sustainability strategies when it comes to product or material cycles, as well as the targeted repair, reuse, modification, waste prevention and upgrading of products, etc.

A product category that is rarely in the public eye is machine tools and special machines. In order to consistently consider sustainability and the associated circular economy in the development of these machines, product developers need practice-oriented and methodically validated decision-making means. The paper discusses and systematizes possible sustainability strategies and their implications from different perspectives, such as business models or applicability.
12:00 noon – 1:30 p.m. Lunch and visits of expositions **12:00 noon – 1:30 p.m. Poster session**

Session 4.2 Systems engineering for demand-oriented products

Time: Tuesday, 05.09.2023
Location: Humboldt building, Lecture room 202
Chairman: S. Husung (D-Ilmenau)

1:30 p.m.	J. Tafur, M. Márquez (PE-Lima), Y. Shardt, A. Gabash (D-Ilmenau)

Optimal Design of a Photovoltaic Station Using Markov and Energy Price Modelling

This paper addresses the optimization of photovoltaic (PV) systems to increase their efficiency. The study introduces a new pricing model that considers the current price of PV inverters. In addition, Markov modeling is used in a new optimization framework to determine the optimal configuration, considering the number of PV modules and inverters, operational constraints, and failure events of PV inverters up to 100 kW. A case study with six real PV inverters confirms the effectiveness of the proposed framework. It calculates the average daily hours of rated power generation considering geographic location, temperature, and solar irradiance using real data from a real PV system. The study identifies both local and global optimal solutions for PV inverters (15 kW to 100 kW), while minimizing the effective levelized cost of energy. The results of the study have important implications for future assessments of PV module failures and repairs.

1:50 p.m.	Z. Lipšinić, N. Pavković (HR-Zagreb)

Integrating life cycle assessment in model-based systems engineering

The emergence of smart products has led to the development of an increasing number of multidisciplinary systems. For the successful development of such systems, a holistic approach is necessary, such as model-based systems engineering (MBSE). It is argued that certain product development activities could be integrated and improved with MBSE, one such activity being the assessment of environmental impacts. This article presents a case study on the usage of Life Cycle Assessment (LCA) on a MBSE system model. In the study a technical system is modelled with views according to the MagicGRID approach. The scope and goal of the LCA are defined by using SysML diagrams and elements. Additionally, different system variants are modelled to explore the capability of comparing LCA studies. At the end of the case study, the benefits, limitations, and shortcomings of the integration are discussed.

2:10 p.m.	Zirui Li, F. Faheem, S. Husung (D-Ilmenau)

Systematic use of model-based solution patterns using the example of a load cell

Complex mechatronic products are usually decomposed into several sub-systems for their development. These sub-systems are developed in parallel or even

independently based on their specifications and use cases. The application of model-based solution patterns is an effective way to comprehensively and efficiently describe the available knowledge about the sub-systems. This contribution proposes an approach to support the selection and application of model-based solution patterns. The approach, based on a metamodel for solution patterns using SysML, describes the process for selecting solution patterns and aligning requirements and constraints with the as-is properties of the sub-systems. Additionally, the approach supports the design of solution patterns taking into account special knowledge from the development of the sub-systems as well as the usage of the solution patterns in different systems and contexts. As an example, an application scenario of a specific load cell within a measurement system is explained.

2:30 p.m.	F. Faheem, Zirui Li, S. Husung (D-Ilmenau)

Analysis of potential errors in technical products by combining knowledge graphs with MBSE approach

Technical products are developed to meet the demands of stakeholders. Therefore, the product's functions and associated properties are important. Various influencing factors e.g., external disturbances can have an impact on the input flows of the products or its characteristics and thus on the functions. If this leads to deviations between the required and as-is functions, these deviations are called errors. It is therefore important to analyze errors in product development and implement measures to increase the robustness of the product. Model-Based Systems Engineering (MBSE) supports the development of complex systems. However, MBSE alone has limited ability to identify in-depth errors. This requires knowledge of possible errors from previous products in specific contexts. For this purpose, the method proposed in this paper facilitates identifying errors in the concept phase by combining MBSE approaches with reusable knowledge (i.e., knowledge graph). The approach is presented using an application example for a mobile robot.

2:50 – 3:10 p.m. Coffee break and visits of expositions	
3:10 p.m.	Mahboob, O. Hussein, L. Willrodt, V. Thanga, M. Takim, H. Hasib, A. Spaans, K. Birkenfeld (D-Munich)

C.Pulse - An industrial demonstrator for a Digital Twin powered by MBSE for achieving digital continuity during the complete development process

The development of complex systems involves a variety both of methods and tools to generate, store and process development-related data and information. This brings Digital Continuity as a key topic for current research. This paper presents a Model-Based Systems Engineering (MBSE) approach that contributes to

achieving Digital Continuity from the early phases of the product development process. This approach has the system architectural specifications at its core, which contains an executable system behaviour model. To provide early verification and validation capabilities, the specification model is enabled with real-time physics simulations and utilizes virtual reality and augmented reality technologies. Furthermore, the same specification model is used to control and communicate with the physical system, collecting real-time data about its operational state, resulting in a Digital Twin while minimizing additional development effort normally necessary for a Digital Twin. The approach is applied to the complete development life cycle of a medical delivery drone.

3:30 p.m.	J. Blott, C. Buchholz (D-Stuttgart)

Challenges of implementing MBSE in Industry - a tool vendor experience

Model-Based Systems Engineering (MBSE) offers a systematic approach to address the challenges faced by industries in developing complex systems. However, the full implementation of MBSE Process, Methods, and Tools (PMT) in industry remains a challenge. This paper focuses on the implementation of the 3DExperience MBSE toolchain by Dassault Systémes Industrial Service (DSIS), introduces the typical challenges observed during the MBSE implementation process and categorizes them into five types. Based on industrial best practices and service experiences, the paper proposes multiple solution elements to overcome these challenges. These elements emphasize stakeholder support, establish an experience-based MBSE capability, enrich MBSE capabilities to solution bricks, create an implementation plan and validate through proof of concepts. The interdependency between solution elements allows efficient implementation and realization of short-term benefits. The paper concludes by discussing the value and applicability of the proposed solution elements, highlighting their potential for the industrial practice. The chapter closes with an outline of future steps to mature and advance the solution elements.

3:50 p.m.	F. Panusch, M. Rienecker (D-Hallstadt), T. Brix, S. Husung (D-Ilmenau)

Systematization of existing uncertainties in the context of product development in the automotive supply industry

Along the development process of technical products, challenges arise repeatedly, which result from uncertainties, i.e., conscious, or unconscious gaps in knowledge or definitions. The causes often lie in the fact that empirical values represent the basis for many decisions, from the specification of tasks to the required organizational and control structures to the models and calculation tools used. Based on this knowledge, it is essential to continuously identify, evaluate

and, if necessary, reduce the degree of uncertainty during the development of innovative products. This is intended to avoid potentially negative influences on the strategic goals of the magic triangle of project management (costs, time, and quality). This is exactly where the investigations started, using the example of an automotive supplier company. Completed projects are the starting point. A first focus is on the analysis of the effects of unclearly defined requirements and ambiguities in verification, validation, and end customer use. A second focus is the systematization, classification up to the provision of project-specific tools, which should facilitate the reduction of uncertainties already in early project phases.

4:10 p.m.	F. Geibel (D-Lohr am Main)

Digital twin in industrial applications – how model-based systems engineering (MBSE) and asset administration shell (AAS) complement each other

In the development, production and usage of cyber-physical systems, the number of stakeholders, involved interfaces and volatile environmental conditions is constantly rising. In addition, use cases require more consideration of the entire system life cycle. This significantly increases the administration effort and forms a barrier for the digital transformation of industrial companies. While model-based systems engineering (MBSE) addresses internal challenges within the product development and Asset Administration Shell (AAS) addresses vendor independent information exchange and interoperability, both approaches need to be coupled to address today's challenges. In this publication typical tasks within product development are discussed: "search the right information", "integrate the right information" and "provide the right information". It is shown how they were approached today, without the alignment of MBSE and AAS, what technological concepts exists to address the challenges and how the tasks are realized by an alignment of MBSE and AAS.

End of session

Session 4.2 Systems engineering for demand-oriented products

Time: Wednesday, 06.09.2023
Location: Humboldt building, Lecture room 202
Chairman: S. Husung (D-Ilmenau)

9:00 a.m.	A. Martin, A. Albers (D-Karlsruhe), F. Weidinger, L. Brinker, S. Wagemann (D-Ditzingen)

Enhancement of an MBSE-supported methodology for managing engineering changes using the example of a machine tool

Engineering changes are often classified as critical and lead to high costs. The reason for this is the high system complexity. To deal with high complexity, MBSE can be used as an approach. However, in order to be able to operate model-based engineering change management, suitable approaches are required. The Advanced Engineering Change Impact Approach - AECIA presents a holistic methodology for model-based change management by supporting change request validity checking, change propagation and change impact analysis, and change information communication in an agile development environment. In this publication, the methodology is extended to include a procedure for checking the validity of change requests, applied to a real change case using a machine tool as an example, and initially evaluated.

9:20 a.m.	C. Mandel, S. Schwarz, A. Albers (D-Karslruhe), S. Husung (D-Ilmenau)

Improving system of objectives maturity through systematic reuse of knowledge using ontology-based knowledge representations

Technical products are developed to meet the needs of different stakeholders. In addition, various constraints from all phases of the product life cycle have to be taken into account. In existing work, this information and its dependencies are systematically represented in the so-called system of objectives. A major challenge in modeling the system of objectives is that the necessary information in the system of objectives is often incomplete and uncertain. In addition, this uncertainty and the maturity of the system of objectives cannot be directly quantified because the target state of the system of objectives often cannot be unambiguously described. This research investigates a methodical approach to assess and improve the maturity of the system of objectives. The two means of reducing uncertainty and thus increasing the maturity of the system of objectives are the systematic reuse of knowledge and the systematic building of knowledge through verification and validation activities.

9:40 a.m.	S. Hartel, C. Faber (D-Landshut)

Using geometric algebra to create differentiable models for optimizing camera-based optical metrology systems

Within the process of designing, implementing and applying camera-based optical metrology systems, many complex and, at first glance, very different optimization tasks arise. For example, finding the best location of a customer specific specimen under test relative to a given sensor or, to a greater extent, finding an optimized geometry of the sensor system itself for a specific measurement scenario. In addition, once the sensor is built, calibration parameters must be determined as accurately as possible. A common yet important task when trying to reach these objectives is to optimize the spatial degrees of freedom of a rigid body, e.g. the pose of a system component or a specimen under test. Of course, modelling the pose of a rigid body is a problem long solved using e.g. rotation matrices and translation vectors, but when it comes to optimizing, this choice of model has severe mathematical drawbacks (gimbal lock, lack of interpolation). Useful concepts such as homogeneous coordinates and (dual) quaternions have been introduced to overcome this – however, due to their very distinct nature, these can quickly become difficult to maintain.

As an alternative, in this contribution it is shown how the methods of geometric algebra can be used to provide a unifying framework for gradient-based optimization of camera-based optical metrology systems – and how this can be done in a generalized way for seemingly different objectives in the context of system design and calibration.

10:20 - 10:40 a.m. Coffee break and visits of expositions

10:40 a.m.	P. Trentsios, M. Wolf, D. Gerhard (D-Bochum)

Towards a deep reinforcement learning integration into model-based systems engineering

The integration of Deep Reinforcement Learning (DRL) in Model-Based Systems Engineering (MBSE) is a promising approach that can lead to significant benefits for system designers and developers. DRL is a branch of machine learning where an agent learns to make decisions by interacting with an environment, receiving feedback in the form of rewards or punishments that indicate the quality of its actions, and adjusting its decision-making policy to maximize the cumulative reward over time. MBSE provides a structured approach to system design, which can help to clarify system requirements, identify potential issues, and improve the overall efficiency of the system development process. This model-based approach can be particularly useful for DRL, which requires a clear understanding of the system environment and objectives to develop the system's behavior.

We propose a method for integrating DRL into MBSE, where the desired system

behavior is defined in a model-based representation using a modeling language to describe the relevant design components for DRL. The method's model framework is applied and evaluated to an example use case using SysML as the modeling language. This integration enables system designers to use DRL with the benefits and support of MBSE.

11:00 a.m.	S. Fincke, R. Maschotta, Y. Hsu, T. Röckl, C. Roßbach, L. Augustin, L. Daubner, J. Deupmann, M. Lehmann, A. Treffurth (D-Ilmenau)

Competence-oriented study in engineering education - examples from the practicing programme

The interdisciplinary and agile processing of projects in teams increasingly characterizes the engineer's work. Problem-solving skills, creativity, entrepreneurship, and initiative, as well as the ability to engage in dialog and conflict resolution, are relevant competencies for this. All engineering students at TU Ilmenau can work on complex interdisciplinary projects in teams (practicING projects) right from the start of their studies. Participants in these practicING projects can also experience significant steps, aspects, and system engineering methods for demand-oriented products. The paper describes the motivation, the learning goals and methodology of practicING projects from the perspective of the supervising teachers and the participating students.Two examples illustrate the potential of the practicING concept: the projects "Wind turbine model with digital twin" and "CrossLab/ experimental ball drop test environment". Experiences in implementing the practicING projects to date are presented, as well as limitations and possibilities for further development.

11:20 a.m.	K.W. Große, F. Flüggen (D-Nordhausen), U. Hirte, T. Brix, S. Husung, F. Hoffmann (D-Ilmenau)

Hybrid teaching and learning environment in the context of virtual product Development

Product development means identifying the needs of different stakeholders, developing a product for them to the point where it is ready for production and use, and documenting it. To manage the complexity of product development, it is becoming increasingly digitalised. As virtual product development is a key area of industry, teaching in this area is an important component of a practice-oriented engineering degree. Engineering education constantly requires new teaching and learning formats. The trend is towards a systematic combination of digital

teaching materials for self-organised individual and cooperative self-study on the one hand, and in-depth forms of classroom teaching tailored to the needs of students on the other - in short, hybrid forms of teaching and learning. Within the framework of an eTeach impulse project for a hybrid teaching and learning environment for virtual product development, important results have been developed, implemented and evaluated to achieve this goal.
12:00 noon – 1:00 p.m. Lunch and visits of expositions

Session 4.3 Metallic and hybrid materials and simulation

Time: Wednesday, 06.09.2023
Location: Humboldt building, Lecture room 201
Chairman: G. Lange (D-Ilmenau)

9:00 a.m.	M. Glaser, J.P. Bergmann, J. Hildebrand, S. Matthes, P. Schaaf (D-Ilmenau)

Characterization of plastic-metal hybrid composites joined by means of reactive Al/Ni multilayers

Present challenges in material science and joining technology are ever more subject to the desire for lightweight construction and engineering. Plastic-metal composites are suitable material combinations but also require the development and investigation of appropriate joining technologies. A particularly promising approach is the application of reactive multilayer foils. As an innovative method, these foils provide the possibility of flexible and low-distortion joining of dissimilar materials. The underlying reaction mechanism offers fast exothermic reaction propagation with well-known exothermic power output while the energy source is introduced directly into the joining zone. In this work, hybrid lap joints between semi-crystalline polyamide 6 and structured austenitic stainless steel X5CrNi18-10 (EN 1.4301) were joined using reactive Al/Ni multilayer foils. The self-propagating reaction provides immediate temperatures that are well above the melting point of used plastic but decays rapidly after only a few milliseconds. To support ongoing investigations regarding composite formation, analysis of occurring thermal regime is in the focus of this work. Conducted experiments are supported by accompanying thermal simulation in ANSYS Workbench. Besides the estimation regarding sensitivity of thermal material parameters the evaluation of formed melting zone and resulting thermally influenced area is a central topic.

9:20 a.m.	M.R.P.M. Tavares, D.A. Rolon, J. Kober, S. Kühne, D. Oberschmidt (D-Berlin), R.B. Schroeter (BR-Santa Catarina)

Molecular dynamics simulation of gallium phosphide zincblende cutting mechanism

Gallium Phosphide (GaP) has a low machinability, due to high tool wear and the need to induce a High-Pressure Phase Transformation (HPPT). HPPT changes GaP crystallographic structure from zincblende to β-tin. The latter is ductile and metastable, therefore, rather than be experimentally observably, must be simulated using atomistic methods. In this work, Classic Molecular Dynamics Simulations (CMDS) were used to analyse GaP HPPT and tool wear mechanisms during the cutting process. Diamond tools were modelled with 10 nm cutting edge radius, -20° and -10° rake angles, and -10° clearance angle. The simulations revealed that the main shear mechanism involved stacking faults, planar dislocations within the

crystal structure, while HPPT had a limited role, being restricted to the deformation zone. A more significant surface crack and tool amorphization were observed for a rake angle -10º.

9:40 a.m.	T. Sprigode, A. Gester, G. Wagner (D-Chemnitz), A. Brückner-Foit, A. Rienäcker (D-Kassel)

Improving weld quality with optimized bobbin tools: an innovative approach to friction stir welding of aluminum

Friction stir welding (FSW) has gained significant attention as a viable method for joining aluminum alloys due to its ability to produce high-quality welds. In recent years, bobbin tools have emerged as an innovative tool geometry for FSW of aluminum. Because of their unique tool design and weld setup, there is no welding pad needed and weak points such as root defects cannot form. The creation of strong and high-quality joints in similar aluminum structures is a challenging task for welding processes. In this regard, the current study aimed to investigate the effect of optimizing the geometry of bobbin tools on the welding behavior and microstructural properties of the joints. To achieve this goal, a simulation of the critical run-in process was initially performed to analyze the contact conditions and welding behavior of this welding set-up. Subsequently, the shape of the tool was optimized using topological optimization to improve the quality of the welding process. The optimized and non-optimized tools were then used to perform FSW on similar aluminum joints made of AA5754. The resulting joints were analyzed for their mechanical and microstructural properties, and it was found that the optimized tool led to a different microstructure and tensile strength than the non-optimized tool. Therefore, this study provides a new and effective approach to improve the weld quality of similar aluminum joints by optimizing the geometry of bobbin tools through simulation.

10:20 - 10:40 a.m. Coffee break and visits of expositions

End of session

Topic 5

Productive teaming - Human-machine collaboration in the production environment

Session 5.1 | Joint cognition
Session 5.2 | Measurement and information collection
Session 5.3 | Information processing
Session 5.4 | Operation and evaluation

Session 5.1 Joint cognition | Session 5.2
Measurement and information collection
Time: Thursday, 07.09.2023
Location: Humboldt building, Lecture hall (HU-HS)
Chairman: M. Ragni (D-Chemnitz)

1:30 p.m.	M. Spiliopoulou, C. Beyer, A. Rother, B. Noack, J. Arlinghaus, (D-Magdeburg), J. Reißmann, A. Hasse, M. Ragni (D-Chemnitz) G. Notni, Ch. Zhang (D- Ilmenau)

Human uncertainty in interaction with a machine: establishing a reference dataset
We investigate the task of label acquisition for malformed object classification, where 'malformed' refers to misshapen, distorted, corroded or broken objects. Despite the progress of artificial intelligence for the classification of objects based on images, the classification of malformed objects still demands human involvement, because each such object is unique. Ideally, the intelligent machine should demand expert support only when it is uncertain about the class. But what if the human is also uncertain? Such a case must be recognized before being dealt with. Goal of this research thread is to establish a reference dataset on human uncertainty for such a classification problem and to derive indicators of uncertainty from sensory inputs. To this purpose, we designed an experiment for an object classification scenario where the uncertainty can be directly linked to the difficulty of labeling each object. By thus controlling uncertainty, we intend to build up a reference dataset and investigate how different sensory inputs can serve as uncertainty indicators for these data. In this work, we describe the planned experiment, and the sensory inputs we intend to capture. Mechanisms for extending this dataset through recordings of further sensors, and workflows for transferring the findings to other classification tasks are planned as future work.

1:50 p.m.	C. Junger, G. Notni (D-Ilmenau)

Qualitative investigations of different closed source registration methods of low-cost deep technologies for human-robot collaboration
Productive teaming is the new form of human-robot interaction. The multimodal 3D imaging has a key role in this to gain a more comprehensive understanding of production system as well as to enable trustful collaboration from the teams. For a complete scene capture, the registration of the image modalities is required. Currently, low-cost RGB-D sensors are often used. These come with a closed source registration function. In order to have an efficient and freely available method for any sensors, we have developed a new method, called Triangle-Mesh-Rasterization-Projection (TMRP). To verify the performance of our method, we

compare it with the closed-source projection function of the Azure Kinect Sensor (Microsoft). The qualitative comparison showed that both methods produce almost identical results. Minimal differences at the edges indicate that our TMRP interpolation is more accurate. With our method, a freely available open-source registration method is now available that can be applied to almost any multimodal 3D/2D image dataset and is not like the Microsoft SDK optimised for Microsoft products.

2:10 p.m.	M. Milosevic, A. Cvetkovic, N. Tomic, E. Petrovic (RS-Nis)

Outage minimization of energy-harvesting wireless sensor network supported by UAV

Due to their adaptability, mobility, and capacity to offer an ideal channel, unmanned aerial vehicles (UAVs) have become a potential option for wireless power transfer and data collection in wireless sensor networks (WSNs). This paper examines energy-constrained WSNs, where data transfer to the data center is facilitated by UAV and sensors rely on radio frequency (RF) energy obtained by a Power Beacon (PB). However, due to energy limitations, sensors can only send data using the harvested energy. We consider a WSN in which the nodes are randomly distributed within a circular area, with the PB placed at the center of the WSN. To evaluate the system performance, we consider the dynamic nature of the wireless channel, which includes factors such as signal reflection, scattering, and diffraction. Through numerical analysis and simulations, the main aim is to identify the optimal system parameters that minimize the outage probability. This analysis provides valuable insights for designing more effective and reliable energy-harvesting WSNs with UAV as data collector. By leveraging UAV in WSNs, system performance can be improved, ensuring data transmission to destination nodes placed at a large distance from the WSN.

2:30 p.m.	K. Jahn, F. Krieglstein, L. L. Chuang, G.D. Rey (D-Chemnitz)

Building an appropriate level of trust with conversational agents as team partners for learning

Conversational artificial intelligence (AI), such as ChatGPT, can be expected to provide new opportunities for educational purposes. For example, conversational AI can assist learners in writing texts, in learning topics from automatically generated summaries, and provide suggestions for further topics. Whereas previous research has often focused on improving trust towards AI (e.g., through anthropomorphic design), research on finding effective ways to develop an appropriate level of trust in AI-based educational scenarios is relatively scarce. Studies in relation to AI-equipped decision support systems have already shown that forcing

users to engage with the information provided through cognitive forcing functions may enhance decisions by creating an appropriate level of trust. Therefore, we aim to test whether these functions can also help to create an appropriate level of trust for conversational AI used for learning, even when the means of improving trust through anthropomorphic design to enhance use are implemented. Here, we present a planned study to investigate this, namely a 2 (cognitive forcing function: learning with the AI generated paper summary first vs. learning with the original paper first) x 2 (anthropomorphic design: lower vs. higher) between-subjects experiment.

2:50 – 3:10 p.m. Coffee break and Visits of Expositions

3:10 p.m.	B. Noack (D-Magdeburg), F. Röhrbein (D-Chemnitz), G. Notni (D-Ilmenau)

Event-based sensor fusion in human-machine teaming

Realizing intelligent production systems where machines and human workers can team up seamlessly demands a yet unreached level of situational awareness. The machines' leverage to reach such awareness is to amalgamate a wide variety of sensor modalities through multisensor data fusion. A particularly promising direction to establishing human-like collaborations can be seen in the use of neuro-inspired sensing and computing technologies due to their resemblance with human cognitive processing. This note discusses the concept of integrating neuromorphic sensing modalities into classical sensor fusion frameworks by exploiting event-based fusion and filtering methods that combine time-periodic process models with event-triggered sensor data. Event-based sensor fusion hence adopts the operating principles of event-based sensors and even exhibits the ability to extract information from absent data. Thereby, it can be an enabler to harness the full information potential of the intrinsic spiking nature of neuromorphic sensors.

3:30 p.m.	T. Mossakowski, F. Neuhaus (D-Magdeburg), M. Hedblom (SE-Jönköping)

Using the diagrammatic image schema language for joint human-machine cognition

Joint human-machine cognitive systems involve cooperation of humans and machines in perception, communication, decision-making and problem-solving tasks. Recently, joint cognition has received increasing attention in the context of productive teaming, which enhances cooperation between humans and machines in the context of production. Here, humans and machines cooperate in a way that enables them to complement each other’s strengths and weaknesses, with the goal of achieving better outcomes than either could achieve alone. For this

purpose, a crucial component is the development of common goals and shared mental models. Hence, the development of a joint cognition will be helpful. While humans are naturally equipped with cognition, machines usually lack a deeper cognitive understanding of both situations and human's intentions. On the way towards a true joint cognition, thus it will be necessary to equip machines with some basic tools for grasping and representing (parts of) human cognition. In this work, we propose to use image schemas as a tool towards this (partial) joint cognition. Image schemas are mental patterns that infants learn from perceptual experiences in an early phase. They represent conceptual forms of embodied, spatiotemporal relationships. We also propose to use the Diagrammatic Image Schema Language (DISL) as an intermediate layer between abstract image schemas and sensorimotor data. This is exemplified with a handover task between a robot and a human.

3:50 p.m.	B. Atitallah, R. Barioul, O. Kanoun (D-Chemnitz), T. Kissinger (D-Ilmenau)

Synergy of nanocomposite force myography and optical fiber-based wrist angle sensing for ambigious sign classification

This paper aims to understand the capabilities and limitations of combining Nanocomposite Force myography sensors (FMG) and optical fiber sensors in standalone systems and their synergy influence on classifying ambiguous hand gestures. A set of 10 highly similar hand signs from the fingerspelling of the American sign language is adopted in this study. Force myography (FMG) signals are collected from one healthy subject performing the selected set of gestures with 40 repetitions for each gesture. The K-Tournament Grasshopper Extreme Learner (KTGEL) classifier has been implemented to perform an automated feature selection and hand sign classification with an efficient network size and high accuracy.

4:10 p.m.	S. Prokhorenko, A. Stadnyk, M. Prokhorenko, T. Bubela (UA-Lviv), M. Moroz (UA-Rivne)

AI-Driven human motion correction and enhancement system with additional manual kinesthetic skill rehabilitation trends

Session 5.3 Information processing |
Session 5.4 Operation and evaluation
Time: Thursday, 07.09.2023
Location: Humboldt building, Lecture room (HU-HS)
Chairman: S. Husung (D-Ilmenau)

9:00 a.m.	F. Ortmeier (D-Magdeburg)

Productive teaming – challenges from the view of trust and safety

Human-machine collaboration always requires guarantees of dependable – i.e. safe and reliable –behavior. Safe means in this context, that no harm is being done to the human (and environment), while reliable means, that even in the case of failures of components (e.g. sensors) or disturbances in the environment (e.g. unforeseen obfuscation of objects), while reliable typically adresse some numerical property about the systems functionality (e.g. mean time to failure). Traditional approaches for production systems rely on either strict separation of work spaces or allow an interleaved "collaboration" (e.g. robot works, robot tops, human works, human leaves, robot works, ...).

For real collaboration, state of the art requires divers safety concepts, which are typically realized by a combination of physical safety and smart sensorics. Safety arguments are then derived in the form of fault tree analyses (FTA). The core idea is here, to systematically decompose a high-level event (e.g.human is hurt) into it's base cause (i.e. component failures). These approaches already come to an edge for simple cooperative scenarios, in which temporal action sequences play a role (e.g. a robot must not enter a certain area while a human is performing a task there). However, this is by far not enough for even simple productive teaming scenarios. For productive teaming, neither action sequences for the human nor for the machine are fixed a priori.In the most simple scenarios, both partners might have at least a partial order of each owns tasks as well as synchronization points. However, in the "normal" case of productive teaming, a human develops his "plan of actions" during work and expects the machine to assist him in a meaningful way. Formally speaking, there does not exist a unique or at least explicit a priori specification of action plans or collaboration sequences. Up to now, such scenarios can not be addressed with any techniques from the dependability domain. In addition user's trust and privacy must not be forgotten. In addition, subjective(!) user's trust in correctness (and safety) of machine behavior is an essential prerequisite for any sort of teaming and privacy must also be guaranteed and designed into the whole systems.

9:20 a.m.	Schwarzkopf. M, Langer D., F. Legler, A. Dettmann, P. Klimant, A.C. Bullinger (D-Chemnitz)

Ergonomic engineering of appropriate levels of trust

The aim of efficient collaborative work with production systems, for instance human-robot-collaboration, is majorly dependent on humans' trust in these systems. Within the last decade, strong interest in the concept of trust in automation and especially trust in robots arose in human factors research. From literature it can be summarized that people trust in automated production systems and robots and that trust rises with time of interaction. This high trust can result in overtrust in automation which is associated with overreliance on and misuse of the system as well as reduced situation awareness and monitoring of the system. To counteract these risks, the concept of Appropriate Trust Level is introduced and defined as the level of trust that is associated with high monitoring and situation awareness but concurrently allows the human to efficiently perform own tasks. This definition is based on observable outcomes with ensures accessibility for measurement. The main research question here is how to make humans trust in the initial collaboration setup and how this can be measured as well as influenced in a methodological way. This research question needs to be extended on defining an appropriate and sufficient level of trust and how to maintain this level during a long-time interaction in industrial work environments. The answering of this question will create the basis for a successful formation of efficient teams of humans and machines in dynamic production processes.

9:40 a.m.	A. Hasse, L.F. Campanile (D-Chemnitz), S. Husung (D-Ilmenau)

An AI-driven design method as basis for teaming in design

The product development process could benefit from a synergistic human-machine teaming, potentially shortening product development cycles and improving product performance and sustainability. However, there is a lack of available methods to achieve this goal. A technical product has to satisfy numerous requirements. Due to the variety and complexity of these requirements, the design process is challenging for human engineers. While engineers are supported by various tools (e.g. FEM) for analyzing product properties, tools for computer-aided synthesis of product properties considering the corresponding requirements are still only available in exceptional cases. However, such synthesis capabilities are necessary to qualify a computer-aided tool for productive teaming with engineers. Special methods based on artificial intelligence show a high potential for general computer-aided synthesis methods. This contribution presents an innovative approach in this direction based on topology optimization techniques.

10:00 a.m.	O. Antons, M. Kessler, J. Arlinghaus (D-Magdeburg)

Designing hybrid intelligence: understanding the impact of human decision-making on AI

Established control approaches struggle to address the increased complexity in a timely manner, leading to a demand for agile methods. Hybrid intelligence and decision support systems are useful approaches to augment human decision-making through artificial intelligence (AI). Various application of AI methods to estimate production parameters or provide forecasts are discussed in the literature, human decision-making is still required either to decide whether to follow specific suggestions or to monitor their respective implementation. However, human behavioral research has shown that human decision-making is rather biased than fully rational, leading to unintended consequences in the collaborative work of humans and machines. The research stream of hybrid intelligence has therefore gained interest recently, aim to study the collaboration between humans and machines. We contribute to this issue by combining a systematic literature review on AI and cognitive biases combined with practical insights from discussions with experts in order to derive first guidelines considering the human factor in the design of AI-based decision support systems for complex production environments

10:20 - 10:40 a.m. Coffee break and visits of expositions	
10:40 a.m.	L. Chuang (D-Chemnitz), A. Raake, W. Broll, E. Domahidi (D-Ilmenau), A. Wendemuth (D-Magdeburg)

Cross-timescale experience evaluation framework for productive teaming

This paper presents the initial concept for an evaluation framework to systematically evaluate productive teaming (PT). We consider PT as adaptive human-machine interactions between human users and augmented technical production systems. Also, human-to-human communication as part of a hybrid team with multiple human actors is considered, as well as human-human and human-machine communication for remote and mixed remote- and co-located teams. The evaluation comprises objective, performance-related success indicators,

behavioral metadata, and measures of human experience. In particular, it considers affective, attentional and intentional states of human team members, their influence on interaction dynamics in the team, and researches appropriate strategies to satisfyingly adjust dysfunctional dynamics, using concepts of companion technology. The timescales under consideration span from seconds to several minutes, with selected studies targeting hour-long interactions and longer-term effects such as effort and fatigue. Two example PT scenarios will be discussed in more detail. To enable generalization and a systematic evaluation, the scenarios' use cases will be decomposed into more general modules of interaction.

11:00 a.m.	T. Hempel, A. Al-Hamadi (D-Magdeburg)

On contextual perception of workers in complex production environments

In this work we focus on the challenges of perceiving and coordinating spatial actions between humans and robots in production systems. We address the fundamental questions of how the affective states of individuals in the production process can be visually captured and interpreted in order to facilitate intuitive interactions without explicit commands. Additionally, we investigate methods to analyze the environment and action context in a semantic scene to anticipate user and action intentions. Lastly, we formulate decision approaches to derive appropriate interaction strategies based on affective user states and intentions in the scene context to improve productive collaboration between humans and robots in production environments. By addressing these challenges, this work aims to improve the efficiency of productive teaming processes in production systems.

Elevator pitches
Sessions 5.1 | 5.2 | 5.3 | 5.4

11:20 a.m.	S. Polley, J. Höbel-Müller, A. Nürnberger (D-Magdeburg)

Can you explain if our team is effectively collaborating?

Explainable AI (XAI) is a rapidly growing research area focused on improving the trustworthiness and interpretability of AI models. We present an idea to address the XAI problem in the context of a team working on a knowledge management task. Our goal is to improve team effectiveness through adaptive explanations in human-machine interactions in teams. We propose to cluster team members based on the similarity of their interactions in solving a task. We use a constrained clustering approach to make a tradeoff between user feedback and explanations. To generate explanations, we suggest relying on multimodal user

feedback that is transformed into modern neural word embeddings and classical signal processing features. By aggregating different aspects of team dynamics, our approach enables adaptation to specific use cases. Our conceptual work contributes to the field of XAI and teamwork in knowledge management tasks.

11:25 a.m.	D. Armbruster, S. Brandenburg, B. Meyer, L. Puricelli, A. Ragni (D-Chemnitz), S. Husung (D-Ilmenau), A. Wendemuth (D-Magdeburg)

Going one step further: Towards cognitively enhanced problem-solving teaming agents

Operating current advanced production systems, including Cyber-Physical Systems, often requires profound programming skills and configuration knowledge, creating a disconnect between human cognition and system operations. To address this, we suggest developing cognitive algorithms that can simulate and anticipate teaming partners' cognitive processes, enhancing and smoothing collaboration in problem-solving processes. Our proposed solution entails creating a cognitive system that minimizes human cognitive load and stress by developing models reflecting humans individual problem-solving capabilities and potential cognitive states. Further, we aim to devise algorithms that simulate individual decision processes and virtual bargaining procedures that anticipate actions, adjusting the system's behavior towards efficient goal-oriented outcomes. Future steps include the development of benchmark sets tailored for specific use cases and human-system interactions. We plan to refine and test algorithms for detecting and inferring cognitive states of human partners. This process requires incorporating theoretical approaches and adapting existing algorithms to simulate and predict human cognitive processes of problem-solving with regards to cognitive states. The objective is to develop cognitive and computational models that enable production systems to become equal team members alongside humans in diverse scenarios, paving the way for more efficient, effective goal-oriented solutions.

11:30 a.m.	R.B. Mendes, E. C. Bellini, L.C. Canno, H.A. Lepikson (BR-Salvador)

Empowering wireless sensor networks with ultra-low power wake-up radio technology with high-band ultrasonic waves and smart IOT-protocol

11:35 a.m.	L. Treybig, S. Werner (D-Ilmenau), J. Höbel-Müller (D-Magdeburg)

Acoustic inter- and intra-room similarity based on room acoustic parameters

This paper shows various approaches for determining acoustic (dis-)similarity based on room acoustic parameter values derived from real measurements. The similarity is calculated across different room configurations and/or between different microphone-loudspeaker positions within the same room configuration. We compare supervised (LDA, Random Forrest) and unsupervised techniques (PCA, SPPA) and pre-selected visualizations in terms of their ability to exhibit inter- and intra-room (dis-)similarities. The data set generated comprises spatially high-resolution room impulse responses obtained from multiple source-receiver positions within a room configuration. The room acoustics are varied by introducing active walls and geometries accounting for specific room configurations. The results show that the separation of room configurations primarily relies on specific acoustic parameters, with the reverberation time playing an important role. Within a given room configuration, the acoustic parameters excluding the reverberation time mainly capture the orientation and distance between the source and receiver.

11:40 a.m.	M. Seeland, D. Scheliga, P. Mäder (D-Ilmenau), R. Altschaffel, J. Dittmann (D-Magdeburg),

Model-based data generation for the evaluation of functional reliability and resilience of distributed machine learning systems against abnormal cases

Future production technologies will comprise a multitude of systems whose core functionality is closely related to machine-learned models. Such systems require reliable components to ensure the safety of workers and their trust in the systems. The evaluation of the functional reliability and resilience of systems based on machine-learned models is generally challenging. For this purpose, appropriate test data must be available, which also includes abnormal cases.

These abnormal cases can be unexpected usage scenarios, erroneous inputs, accidents during operation or even the failure of certain subcomponents. In this work, approaches to the model-based generation of an arbitrary abundance of data representing such abnormal cases are explored. Such computer-based generation requires domain-specific approaches, especially with respect to the nature and distribution of the data, protocols used, or domain-specific communication structures. In previous work, we found that different use cases impose different requirements on synthetic data, and the requirements in turn imply different

generation methods [Makrushin et al. 2023]. Based on this, various use cases are identified and different methods for computer-based generation of realistic data, as well as for the quality assessment of such data, are explored. Ultimately we explore the use of Federated Learning (FL) to address data privacy and security challenges in Industrial Control Systems. FL enables local model training while keeping sensitive information decentralized and private to their owners.
In detail, we investigate whether FL can benefit clients with limited knowledge by leveraging collaboratively trained models that aggregate client-specific knowledge distributions. We found that in such scenarios federated training results in a significant increase in classification accuracy by 31.3% compared to isolated local training. Furthermore, as we introduce Differential Privacy, the resulting model achieves on par accuracy of 99.62% to an idealized case where data is independent and identically distributed across clients.

11:45 a.m.	S. Stober, V. Krug, M. Ebrahimzadeh (D-Magdeburg)

XAI for building a foundation of trust in productive teams
Trust is a crucial component for the success of any team, whether it is made up of humans only or a combination of humans and machines. When team members trust each other, they are more likely to communicate openly, collaborate effectively, and work towards common goals. This is especially important for teams that include both humans and machines, as the integration of technology can sometimes be a source of tension and mistrust.
Explainable AI (XAI) is a type of artificial intelligence that is designed to be able to explain its decision-making processes to humans in a way that is easy for them to understand. Since 2017, we have been exploring new XAI techniques with a specific focus on deep learning models (1) for audio analysis tasks such as speech recognition or audio event detection, and (2) for applications in medical imaging – most importantly within the project ``CogXAI – Cognitive neuroscience inspired techniques for eXplainable AI". We propose to build on our results of the CogXAI project and investigate how XAI techniques can play a critical role in building trust between humans and machines in hybrid productive teams. To this end, we here present selected techniques developed within CogXAI that we aim to adapt and further elaborate on within the context of Productive Teaming.

12:00 noon – 1:30 p.m. Lunch and visits of expositions
12:00 noon – 1:30 p.m. Poster session

Workshops

WS 1 | Living Glass Surfaces XII
WS 2 | Mechanical and precision engineering – Methods, tools and application for the 21st Century

Workshop "Living Glass Surfaces XII"

Wednesday, 06.09.2023
Location: Humboldt building, Lecture room 210
Chair: E. Rädlein (D-Ilmenau)

9:00 a.m.	E. Rädlein (D-Ilmenau)
Welcome speech and program introduction	
9:20 a.m.	G. Strugaj (D-Ilmenau)
The future of glass	
	Elevator pitches
09:50 a.m.	D. Stock (D-Jena)
Structural and topological properties of the interface between amorphous silica and sodium tetrasilicate glass: Implications for sodium transport	
09:55 a.m.	E. Ilser (D-Ilmenau)
Entwicklung eines weißdeckenden Glasemails	
10:00 a.m.	L. Knüpfer (D-Göttingen)
Longterm alteration of silicate glass fibres studied by SEM	
10:05 a.m.	M. Lüdermann, E. Rädlein (D-Ilmenau)
Ortsaufgelöste Charakterisierung von Verkapselungsfolien für Solarzellen	
10:10 a.m.	A. Weiss (D-Ilmenau)
Evaluation von Quarzglasausschuss hinsichtlich eines effizienten Nutzungskonzeptes	
10:20 - 10:40 a.m. Coffee break and visits of expositions	
10:40 a.m.	M. Benisch (D-Deggendorf)
Consideration of sensory approaches for the sustainable manufacture of optical components	

11:10 a.m.	Ch. Wünsche (D-Deggendorf)
Footprint of polishing processes	
11:30 a.m.	R. Hassel (D-Jena)
Untersuchungen zur schichtweisen Verfestigung von Alkalisilicatglas-Lösungen mittels CO2-Laserstrahlung	
12:00 noon – 1:00 p.m. Lunch and visits of expositions	

Workshop "Living Glass Surfaces XII"

Thursday, 07.09.2023
Location: Humboldt building, Lecture room 210
Chair: E. Rädlein (D-Ilmenau)

9:20 a.m.	T.I. Kwinda (D-Leipzig)
Development of porous silica-alumina glasses with enhanced hydrothermal stability for biomass conversion.	
09:50 a.m.	J. Wessel (D-Ilmenau)
Ionenleitfähigkeit in Lithiumborosilicatgläsern	
10:20 - 10:40 a.m. Coffee break and visits of expositions	
10:40 a.m.	W. Langgemach (D-Dresden)
Bend it like…- a contribution to investigations of the fatigue behavior of flexible glass	
11:10 a.m.	Y.P. Hartmann, J. Burkard (D-Ilmenau)
Lichtschichtmikroskopie an einer Ce-YAG Glaskeramik	
11:40 a.m.	Networking
Discussing research ideas. Exchange of information. Career opportunities.	
12:00 noon – 1:30 p.m. Lunch and visits of expositions **12:00 noon – 1:30 p.m. Poster session**	

Workshop "Mechanical and precision engineering – Methods, tools and application for the 21st Century"

Friday, 08.09.2023
Location: Humboldt building, Lecture hall (HU-HS)
Chairman: St. Husung (D-Ilmenau)

9:00 a.m.	Opening
	Greetings
	Scientific Presentations
10:20 a.m. – 10:40 p.m. Coffee break	
10:40 a.m.	Scientific Presentations
12:00 noon End of workshop	

Social events

Welcome reception
Excursion and conference dinner

Welcome reception

Monday, 04.09.23
5:00 – 7:00 p.m.

We kindly invite you to the welcome reception held in the foyer of the Humboldt building. Weather permitting, the welcome reception will be given outdoor.

Please notice

Wearing your name badge is obligatory and entitles you to free participation and enjoyment of the Thuringian specialities.

Please enjoy Thuringia's hospitability.

Social events

Excursion and conference dinner

Wednesday 06.09.23 3:15 p.m.	Coach depart from the Refectory (Mensa Dining Hall) for the Excursion to Erfurt.
Excursion programme	**Welcome to the capital of Thuringia and to the Protestant Augustinian Monastery in Erfurt**
4:00 p.m.	Erfurt is not only the capital of Thuringia - it impresses especially with its historical ensemble, for example St. Mary's Cathedral, St. Severie Church, Krämer Bridge, also the cityscape. Experience the fascination of a historical city during an interesting walking tour, which we start from the cathedral square.
5:30 p.m.	Participants can expect a 30-minute concert on the Walcker organ in the Augustinian monastery directly afterwards, before the monastery opens its doors for a 1-hour guided tour.
7:00 – 10:00 p.m.	The conference dinner will take place in the charming historic atmosphere of the Luther Hall.
10:30 p.m.	The return journey takes place at 22:30 from the cathedral square.
Admission	**€ 78 incl.** (19 % VAT (€ 12,45) on € 65,55 net total) The price covers the journey by coach, the guided city tour, the organ concert, the monastery guided tour and the conference dinner with welcoming drink and selected beverages.
Please notice	Wearing your name badge is obligatory and entitles you to the participation.

List of Main Authors/Chairmen

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