Department of Intelligent Technologies

Institute of Fundamental Technological Research

Progress in the design of new structures
seems to be unlimited

/Klaus–Jürgen Bathe, 1967/

Main research topics

1. Structural health monitoring (SHM)
2. Adaptive systems & optimum control
3. Dynamics of structures and machines
4. Vibroacoustics
5. Mobile robotics
6. Other topics (ballistic & blast protection, optimum design of structures, additive manufacturing & surface engineering, prestressed composites)

Labs

Structural health monitoring (SHM)

Motivation

Local nondestructive testing techniques are time-consuming, expensive and require a direct access to the entire structure.
Automatized response-based monitoring is the solution.

Timeliness

- always lower costs of wireless sensing systems
- extensive instrumentation of public structures, esp. in East Asia

Research problems

1. Damage detection, localization and quantification[1,2]
2. Optimum sensor placement, sensitivity analysis[3], substructuring
3. Indirect monitoring of loads (magnitude, location, trajectory)

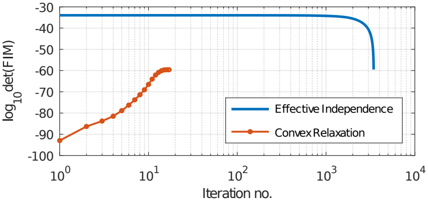
[1] Y.An, E.Chatzi, S.Sim, S.Laflamme, B.Błachowski, J.Ou, Recent progress and future trends on damage identification methods for bridge structures, *Structural Control & Health Monitoring* 26(10):e2416, 2019.

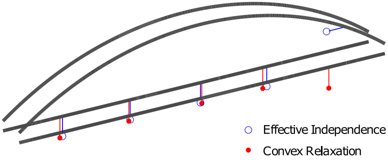
[2] J.Hou, C.Li, Ł.Jankowski, Y.Shi, L.Su, S.Yu, T.Geng, Damage identification of suspender cables by adding virtual supports with the substructure isolation method, *Structural Control & Health Monitoring* 28:e2677, 2021.

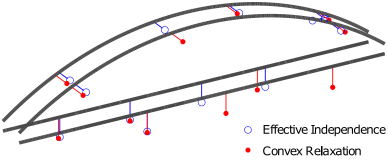
[3] J.Hou, Z.Li, Ł.Jankowski, S.Wang, Estimation of virtual masses for structural damage identification, *Structural Control & Health Monitoring* 27(8):e2528, 2020.

Structural health monitoring (SHM)

Optimum sensor placement by convex relaxation[4]







[4] B.Błachowski, A.Świercz, M.Ostrowski, P.Tauzowski, P.Olaszek, Ł.Jankowski, Convex relaxation for efficient sensor layout optimization in large-scale structures subjected to moving loads, *Computer-Aided Civil and Infrastructure Engineering* 35(10):1085–1100, 2020.

Adaptive systems & optimum control

Inspiration: In nature, dynamic optimum self-adaptation to varying external conditions is ubiquitous.

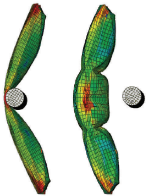
Semi-active control

changes in local mechanical properties of structural elements[5,6]

(effective stiffness, damping, moment-transfer ability, yield stress, etc.)

***vs.* active control**

- no large external control forces
- very low energy consumption
- low danger of instabilities

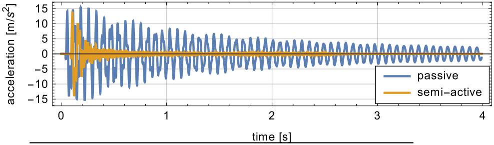


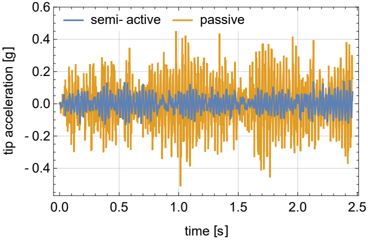
[5] M.Wasilewski, D.Pisarski, Adaptive semi-active control of a beam structure subjected to a moving load traversing with time-varying velocity, *Journal of Sound and Vibration* 481:115404, 2020.

[6] M.Michajłow, Ł.Jankowski, T.Szolc, R.Konowrocki, Semi-active reduction of vibrations in the mechanical system driven by an electric motor, *Optimal Control, Application and Methods* 38(6):922–933, 2017.

Adaptive systems & optimum control

1. **Adaptive damping of vibrations**[7,8]
   - dynamic reconfiguration of flexible structures[9]
   - distributed & decentralized control of modular structures[10]
2. **Adaptive impact absorption**[11]
   - adaptive pneumatic structures
   - kinetic energy management





[7] M.Wasilewski, D.Pisarski, C.I.Bajer, Adaptive optimal control for seismically excited structures, *Automation in Construction* 106:102885, 2019.

[8] D.Pisarski, Decentralized stabilization of semi-active vibrating structures, *Mechanical Systems and Signal Processing* 100:694–705, 2018.

[9] B.Poplawski, G.Mikulowski, R.Wiszowaty, Ł.Jankowski, Mitigation of forced vibrations by semi-active control of local transfer of moments, *Mechanical Systems and Signal Processing* 157:107733, 2021.

[10] D.Pisarski, R.Konowrocki, Ł.Jankowski, Scalable distributed optimal control of vibrating modular structures, *Structural Control and Health Monitoring* 27(4), e2502, 2020.

[11] C.Graczykowski, R.Faraj, Development of control systems for fluid-based adaptive impact absorbers, *Mechanical Systems and Signal Processing* 122:622–641, 2019.

Adaptive systems & optimum control

3. **Actuators for semi-active control**
   - pneumatic/hydraulic, inerters[12], granular[13], shunted piezo
   - optimum actuator placement
   - local predictive control[14]

4. **Other adaptive systems**
   - self-deployable structures for high-altitude aerostats[15,16] and space structures
   - real-time, energy-optimum flight trajectories for UAVs

[12] R.Faraj, Ł.Jankowski, C.Graczykowski, J.Holnicki-Szulc, Can the inerter be a successful shock-absorber? The case of a ball-screw inerter with a variable thread lead, *Journal of the Franklin Institute* 356(14):7855–7872, 2019.

[13] J.M.Bajkowski, B.Dyniewicz, M.G ebik-Wrona, J.Bajkowski, C.I.Bajer, Reduction of the vibration amplitudes of a harmonically excited sandwich beam with controllable core, *Mech Syst Signal Proc* 129:54–69, 2019.

[14] R.Faraj, C.Graczykowski, Hybrid prediction control for self-adaptive fluid-based shock-absorbers, *Journal of Sound and Vibration* 449:427–446, 2019.

[15] L.Knap, A.Świercz, C.Graczykowski, J.Holnicki-Szulc, Self-deployable tensegrity structures for adaptive morphing of helium-filled aerostats, *Archives of Civil and Mechanical Engineering* 21:159, 2021.

[16] L.Knap, C.Graczykowski, J.Holnicki-Szulc, Z.Wołejsza, Strategies for reduction of energy consumption during ascending and descending process of modern telescopic HAPS aerostats, *Bulletin of the Polish Academy of Sciences: Technical Sciences* 68(1):155–168, 2020.

Dynamics of structures and systems

1. **Dynamics of structures under moving loads**[17]
   - track and railbed systems
2. **Dynamics of massive high-speed rotorshafts**[18,19]
   (gas turbines, turbochargers, beater mills, crushers)
   - torsional vibrations, touchless bearing systems, unbalances
3. **Electro-mechanic coupled vibrations in drive systems**
   - transient and quasistatic states

[17] B.Dyniewicz, C.I.Bajer, K.L.Kuttler, M.Shillor, Vibrations of a Gao beam subjected to a moving mass, *Nonlinear Analysis: Real World Applications* 50:342–364, 2019.

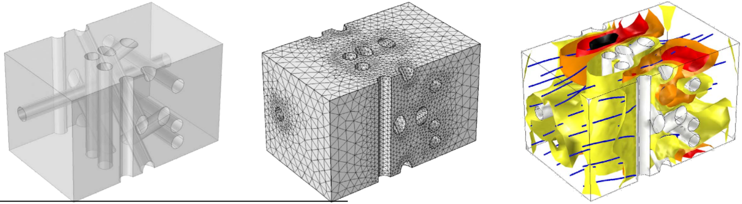
[18] T.Szolc, R.Konowrocki, Research on stability and sensitivity of the rotating machines with overhung rotors to lateral vibrations, *Bulletin fo the Polish Academy of Sciences: Technical Sciences* 69(6):e137987, 2021.

[19] P.Kurnyta-Mazurek, T.Szolc, M.Henzel, K.Falkowski, Control system with a non-parametric predictive algorithm for a high-speed rotating machine with magnetic bearings, *Bulletin fo the Polish Academy of Sciences: Technical Sciences* 69(6):e138998, 2021.

Vibroacoustics

Multiscale vibroacoustics[20] & poroelastic meta-materials[21]

1. optimum enclosure & microstructure design[22,23]
2. 3D printing & experimental evaluation[24]
   - sound absorption & propagation control
   - pores, inclusions, membranes, ...



[20] M.Meissner, Application of modal expansion method for sound prediction in enclosed spaces subjected to boundary excitation, *Journal of Sound and Vibration* 500:116041, 2021.

[21] R.Venegas, T.G.Zieliński, G.Núñez, F.-X.Bécot, Acoustics of porous composites, *Composites Part B: Engineering* 220:109006, 2021.

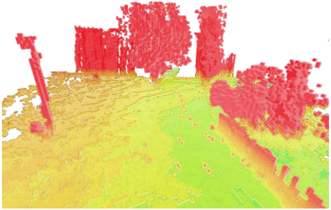
[22] S.Ahsani, C.Claeys, T.G.Zieliński, Ł.Jankowski, F.Scarpa, W.Desmet, E.Deckers, Sound absorption enhancement in poro-elastic materials in the viscous regime using a mass–spring effect, *J Sound Vib* 511:116353, 2021.

[23] T.G.Zieliński, R.Venegas, C.Perrot, M.Červenka, F.Chevillotte, K.Attenborough, Benchmarks for micro-structure-based modelling of sound absorbing rigid-frame porous media, *J of Sound and Vib* 483:115441, 2020.

[24] K.C.Opiela, T.G.Zieliński, Microstructural design, manufacturing and dual-scale modelling of an adaptable porous composite sound absorber, *Composite Part B: Engineering* 187:107833, 2020.

Mobile robotics

1. simultaneous mapping, localization and autonomous navigation[25,26]
2. modular manipulators[27] and structures[28]
3. task planning in multiagent robot systems



Applications

– manipulators & mobile robots
– UAVs for 3D mapping of structures[29] and health monitoring

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[25] M.Pełka, J.Będkowski, Calibration of planar reflectors reshaping LiDAR's field of view, *Sensors* 21:6501, 2021.

[26] J.Będkowski, T.Röhling, Online 3D LIDAR Monte Carlo localization with GPU acceleration, *Industrial Robot: An International Journal* 44(4):442–456, 2017.

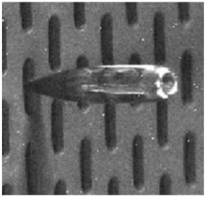
[27] M.Zawidzki, J.Szklarski, Transformations of Arm-Z modular manipulator with Particle Swarm Optimization, *Advances in Engineering Software* 126:147–160, 2018.

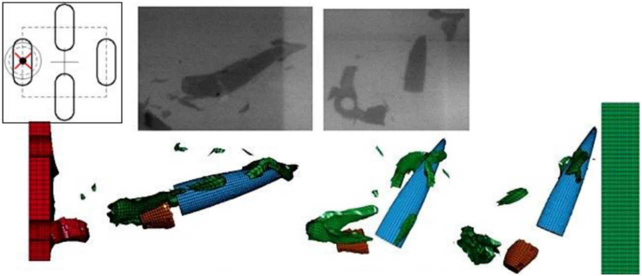
[28] M.Zawidzki, Ł.Jankowski, Multiobjective optimization of modular structures: weight versus geometric versatility in a Truss-Z system, *Computer-Aided Civil and Infrastructure Engineering* 34:1026–1040, 2019.

[29] J.Będkowski, K.Majek, P.Majek, P.Musialik, M.Pełka, A.Nüchter, Intelligent mobile system for improving spatial design support and security inside buildings, *Mobile Networks and Applications* 21(23):313–326, 2016.

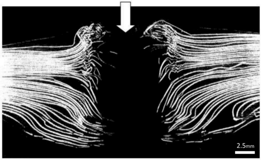
Other topics: Ballistic and blast protection

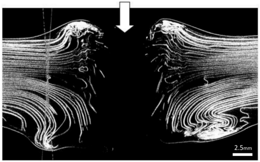
Defeat mechanism provided by slotted add-on plates[30]





Performance of Li-ion pouch battery under a high-velocity impact[31]



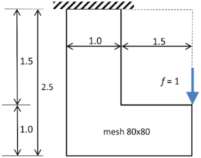


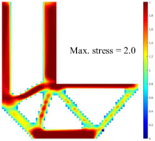
[30] T.Frąś, A.Murzyn, P.Pawłowski, Defeat mechanisms provided by slotted add-on bainitic plates against small-calibre 7.62 mm x 51 AP projectiles, *International Journal of Impact Engineering* 103:241–253, 2017.

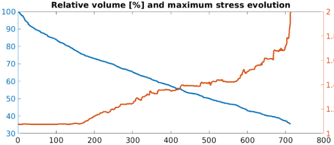
[31] T.Fras, P.Pawlowski, W.Li, T.Wierzbicki, Performance of Li-ion pouch battery under a high-velocity impact: experiment and numerical simulation, *International Journal of Impact Engineering* 155:1039152, 2021.

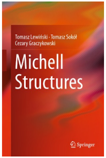
Other topics: Optimum design of structures

Topology optimization (elastoplastic[32,33] and Michell[34] structures)

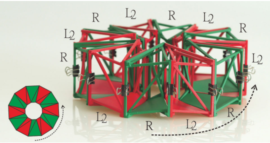


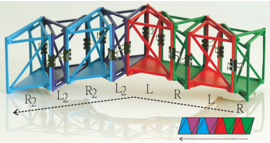


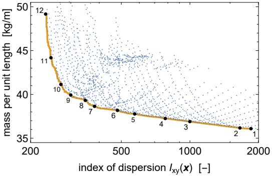




Structural optimization of modular structures[35]







32 B.Błachowski, P.Tauzowski, J.Lógó, Yield limited optimal topology design of elastoplastic structures, *Structural and Multidisciplinary Optimization* 61:1953–1976, 2020.

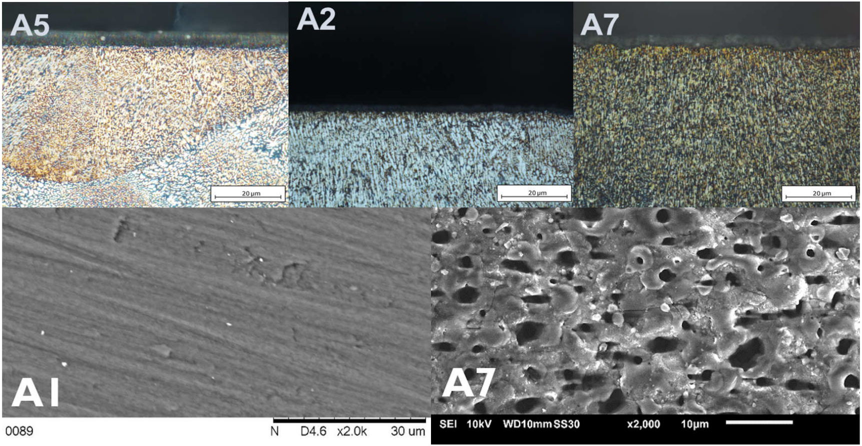
33 P.Tauzowski, B.Błachowski, J.Lógó, Topology optimization of elasto-plastic structures under reliability constraints: a first order approach, *Computers and Structures* 243:106406, 2021.

34 T.Lewiński, T.Sokół, C.Graczykowski, *Michell Structures*, Springer, 569 pages, 2019.

35 M.Zawidzki, Ł.Jankowski, Multiobjective optimization of modular structures: weight versus geometric versatility in a Truss-Z system, *Computer-Aided Civil and Infrastructure Engineering* 34(11):1026–1040, 2019.

Other topics: Additive manufacturing & surface engineering

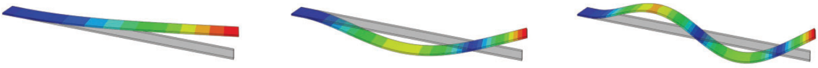
Plasma electrolytic oxidation of AlSi10Mg alloy manufactured by selective laser melting of metallic powders



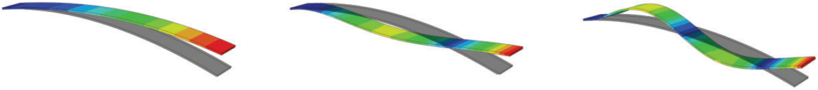
Other topics: Prestressed composite materials

1. manufacturing process (experiment, modeling)
2. analysis & monitoring of the operational properties[36,37] (static, dynamic & rheological)
3. optimal design of structures

Non-prestressed sample: mode shapes



Prestressed sample: mode shapes

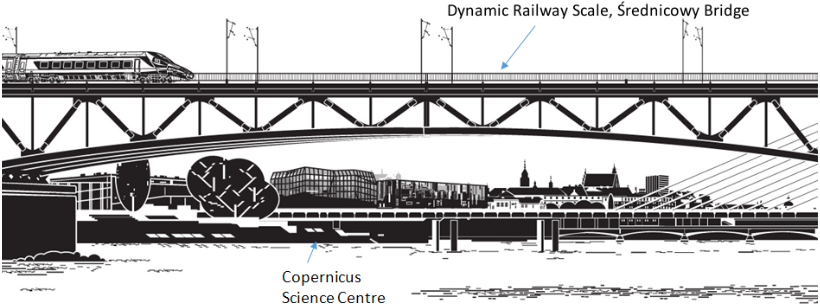


[36] A.Orłowska, C.Graczykowski, A.Galezia, The effect of prestress force magnitude on the natural bending frequencies of the eccentrically prestressed glass fibre reinforced polymer composite beams, *Journal of Composite Materials* 52(15):2115–2128, 2018.

[37] A.Orłowska, A.Gałęzia, A.Świercz, Ł.Jankowski, Mitigation of vibrations in sandwich-type structures by a controllable constrained layer, *Journal of Vibration and Control* 27:1595–1605, 2021.

Labs

1. Safety Engineering Lab
2. Safety Systems Lab in Jabłonna (KEZO PAN)
3. 4 field test stands
   (2x railway bridge, 1x footbridge, 1x football stadium)
4. 2 small labs (electronics, mobile robotics/vibroacoustics)



Safety Engineering Lab

Safety Systems Lab

in KEZO PAN, Jabłonna

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