

# MECHATRONICS RESEARCH INFRASTRUCTURE

## 1. Equipment for hot melt extrusion and 3D printing of polymeric materials

- 1.1 Melt compounding and filament extrusion system based on Noztek fusionX or Noztek Touch (with filament tensioning device Noztek Tolerance Puller, filament spooling device Winder 2.0, filament air and water coolers).
- 1.2 SLS-type 3D printer EOS Formiga P110 (material – Polyamide 12 powder).
- 1.3 SLA-type 3D printer Stratasys Objet30 (material – photopolymer).
- 1.4 FDM-type 3D printer Stratasys Dimension BST 768 (material – ABS filament).
- 1.5 FDM-type 3D printers: Ultimaker 2, Ultimaker S5, Prusa, etc.

## 2. Biomechatronics equipment

- 2.1 High-speed multi-camera 3D motion capture and analysis system by Qualisys AB based on 300 fps cameras Oqus 7+ including analysis software Visual3D.
- 2.2 High-accuracy force measuring platforms AMTI Optima 400600 for full gait cycle analysis (synchronized with Qualisys 3D motion analysis system).
- 2.3 On-body wireless 3D kinematics measurement system for real-time human motion tracking based on inertial sensors (with 60 Hz update rate): MVN BIOMECH Awinda + software MVN Studio BIOMECH (Xsens Technologies B.V.).
- 2.4 Pressure mapping in-shoe sensing system for foot function & gait analysis F-Scan (Tekscan Inc.) and OpenGo Science (Moticon GmbH) for analysis of contact forces of the human foot.
- 2.5 Balance analysis system Balance SD (Biodex Medical Systems Inc.).
- 2.6 A set of training equipment: i) specialized treadmill with integrated force plate FDM-THM-S (HP, Zebris Medical GmbH); ii) stationary bicycle; iii) rowing machine; iv) small devices for different training (balance platforms and etc.)
- 2.7 Digital ultrasound diagnostics system (2D and M mode) LogicScan 128 CEXT-1Z with Echo Wave II (Telemed Ltd).
- 2.8 Wireless telemetric EMG system TeleMyo DTS 2400R G2 (Noraxon Inc.) with a set of various sensors: force transducers, goniometers, inclinometers, accelerometers, hand dynamometers and foot switches.
- 2.9 Portable wireless EEG recorder BE Micro (EB Neuro S.p.A.).
- 2.10 EEG-based neuroheadset Emotiv EPOC.
- 2.11 Wearable telemetric metabolic measurement system Cosmed K5 based on exhaled gas sensing.
- 2.12 Anthropometric kit: BSL MP36 (Biopac Inc.), "Harpenden" anthropometer (Holtain Ltd.), segmental body composition analyzer Tanita BC-418.
- 2.13 Digital acoustic noise measurement and creation instruments: K-Array KR202, Yamaha MGP12X, Sony DWZ M50, NTI AL1 + NTI mini SPL.
- 2.14 Virtual reality simulation system Cyber-I, head-mounted display Visette 45 SXGA.
- 2.15 Isokinetic dynamometer HUMAC NORM 770 (CSMi Solutions) with a set of various adaptors for hands, legs and back analysis and training.

### 3. Vibration testing tools

- 3.1 A set of Polytec laser Doppler vibrometers (LDV) for in-depth dynamic characterization of both macro- and micro-scale structures:
  - 3.1.1 Full-field 3D scanning LDV system Polytec PSV-500-3D-HV for full modal analysis of mini & macro structures (up to 25 MHz).
  - 3.1.2 Microscope-based optical testing system Polytec MSA-500-TPM for out-of-plane/in-plane vibration and topography measurements of MEMS components. The system may be mounted onto manual or vacuum probe station (Cascade Microtech PMS150 or PLV50) for measurements both in ambient conditions or in high vacuum at elevated temperatures (up to  $10^{-5}$  mbar &  $+200^{\circ}\text{C}$ ).
  - 3.1.3 Single-point high-sensitivity autofocus LDV system Polytec OFV-505 + OFV-5000.
  - 3.1.4 Single-point fiber-optic differential LDV system Polytec OFV-512 + OFV-5000.
  - 3.1.5 Rotational laser vibrometer Polytec RLV-5500.
- 3.2 Digital holographic interferometry system HYTEC PRISM for full-field real-time measurements of displacement and deformation fields.
- 3.3 CCD laser displacement sensor Keyence LK-G82 + LK-G3001PV for vibration measurements (1 Hz – 20 kHz).
- 3.4 Electrodynamic shaker with closed-loop vibration control B&K LDS V555 + PA1000L + Type 7542 for dynamic testing of various structures up to 25 kg (harmonic, random, shock excitation in a 20 Hz – 6.3 kHz range with acceleration up to 100g).
- 3.5 Compact electromagnetic shaker Wilcoxon F4 (with impedance head Z7 for acceleration & force measurements) and piezoelectric shaker Wilcoxon F7-1.
- 3.6 Vibration signal analyzer B&K PULSE Type 3560C.
- 3.7 Accelerometers:
  - 3.7.1 B&K. Charge-type models: 4371 (general-purpose), 4374-S (subminiature), 8309 (high-g & wideband: for shocks), charge-to-Deltatron converter Model 2647. IEPE models: 4513-B-002 (high-sensitivity, TEDS) & 4519-003 (miniature).
  - 3.7.2 MEGGITT Endevco. High-temperature charge-type Models 2276 & 2248 (miniature), triaxial IEPE Models 66A50-X & 66A11.
  - 3.7.3 MMF Metra. Charge-type KS93 (miniature), KD91.
- 3.8 B&K microphones Models 4191-B-001 & 4939-B-002. B&K force transducer Model 8230-003.
- 3.9 A set of vibration-isolation tables (Standa Ltd).

### 4. Mechanical testing and characterization tools

- 4.1 Multi-module indentation (MHT) & scratch (MST) measurement system OPX-MCT by CSM Instruments (Anton Paar).
- 4.2 Rheometer Anton Paar MCR302 (with PS-MRD, PP20/MRD and TG/MRD) for characterization of MR fluids.
- 4.3 High-speed impact tester: a customized version of FW Magnus 1000 50m/s (Coesfeld GmbH & Co. KG).

- 4.4 Linear-torsional cyclic testing machine Instron E10000 (10 kN, dynamic testing up to 100 Hz, stroke up to 60 mm, temperature range: -70...+350°C). The machine is integrated with: (i) non-contact full-field displacement/shape/strain measurement 3D-DIC system from Correlated Solutions (VIC-2D/3D, VIC-Gauge 2D/3D, 20 fps @ 12 MPx, lenses: Basler Lens 25 mm, Rodenstock Rodagon 80 mm); (ii) clip-on high temperature un-cooled axial extensometer 7642-010M-025M, clip-on high temperature crack opening displacement (COD) gage 7641-010M-100M, clip-on axial/torsional extensometer 3550-025M-005-003-ST; (iii) load cells Dynacell 2527-202 (10kN, 100 Nm) and Dynacell 2527-131 (0.25 kN).
- 4.5 Dual-column static tensile testing machine Tinius Olsen H25KT (25 kN) including a set of grips for hard and soft materials.
- 4.6 Coordinate measuring machines: Mitutoyo CRYSTA-Apex S 9106, DEA GLOBAL Silver Performance.
- 4.7 2-components dynamometer with signal conditioner Kistler 9345B + 5018A1003 for measurements of axial force (up to 10 kN) and torque (up to 25 Nm).
- 4.8 Portable roughness meter Mitutoyo SJ-210.
- 4.9 Digital force/torque gauge Mark-10 Series BGI (with force sensor SS-50 (up to 250 N) and torque sensor STJ-100 (up to 10 Nm).
- 4.10 Mitutoyo instruments: 3D measuring microscope Quick Vision active 202, toolmakers measuring microscope TM-505B, contour measurement system CONTRACER CV-2100, hardness tester HR-530 (Rockwell, Rockwell Superficial, Rockwell testing of plastics (A&B), Light Force Brinell hardness), Micro-Vickers hardness tester HM-200, linear height gauge LH-600E, high-accuracy micrometer 293-100-20 (range 0-25 mm, resolution 0.0001 mm), Shore A plastic and rubber hardness tester.

## 5. Robotics equipment

- 5.1 ABB industrial robots: IRB 1200, IRB 120, 2xIRB 360.
- 5.2 Collaborative humanoid robot for assembly automation ABB YuMi IRB 14000.
- 5.3 5-fingered robot hand HIRO.
- 5.4 Humaniform robot hand Shadow Dexterous Hand.
- 5.5 Personalizable and interactive humanoid robot NAO V5 (Aldebaran Robotics).
- 5.6 Mobile robotics device Festo Robotino and a set of robotics-related devices and accessories.
- 5.7 A set of various laboratory-grade analysis and demonstration tools for mechatronics/robotics investigations (ITT Group HL01 Robotic HomeLab Basic kit, ITT Group HL02 Robotic HomeLab Add-On kit).
- 5.8 Small-scale automated assembly line by FESTO for training purposes.

## 6. Infrared & high-speed cameras

- 6.1 Digital high-speed cameras:
  - 6.1.1 Phantom v711 (7.5K fps @ 1280×800, max: 1.4M fps @ 128×8).
  - 6.1.2 MOTION PRO 10000.
- 6.2 Infrared cameras:
  - 6.2.1 High-speed & high-sensitivity IR camera FLIR SC7500 (380 Hz @ 320×256, max: +3000°C, 39.8 kHz @ 64×4, 12 mm and 50 mm lenses).
  - 6.2.2 Portable IR camera with LCD display FLIR T450sc (60 Hz @ 320×240, max +1500°C).
  - 6.2.3 Compact IR camera ThermoVision A-20M (60 Hz @ 160×120).

## 7. 3D laser scanners

- 7.1 Portable 3D laser scanner FARO Focus<sup>3D</sup> X 130 for accurate ( $\pm 2$  mm) and mid-range (0.6 – 130 m) measurements of various complex structures, large-volume components, building facades, etc.
- 7.2 Portable 7-axis measuring arm with integrated high-performance 3D laser scanner FARO Edge ScanArm for ultrahigh-resolution (contact mode:  $\pm 0.034$  mm) and short-range (up to 1.8 m) measurements.
- 7.3 Handheld self-positioning 3D laser scanner Creaform Go!Scan 50 for high-resolution ( $\pm 0.5$  mm) and high-speed measurements in full color (component size range: 0.3 – 3 m).
- 7.4 Handheld self-positioning 3D laser scanner Creaform HandySCAN 700 for very high-resolution ( $\pm 0.05$  mm) and high-speed measurements in full color (component size range: 0.1 – 4 m).

## 8. Optical microscopes

- 8.1 Motorized (z axis) microscope Nikon Eclipse LV100ND (objectives:  $\times 5 \dots \times 100$ ): episcopic/diascopic illumination, 16 MPx FX-format CMOS digital camera DS-Ri2 (capture of low-noise color images: up to 6 fps @ 4908 $\times$ 3264, 45 fps @ 1636 $\times$ 1088), imaging software NIS-Elements (EDF, stereovision, 3D surface, TimeLapse, Macro, etc.).
- 8.2 Manual microscope Nikon Eclipse LV150 with monochrome digital camera Infinity 1-1.

## 9. Electrical measuring instruments and tools

- 9.1 Probe stations for MEMS electrical testing: Cascade Microtech PMS150 (manual) and PLV50 (vacuum, +200°C).
- 9.2 2-channel wide-range high-resolution SMU Keithley SourceMeter 2614B ( $\pm 200$  V,  $\pm 1.5$  A DC).
- 9.3 Precision impedance analyzer Wayne Kerr Electronics 6510B (20 Hz – 10 MHz).
- 9.4 Spectrum analyzer GW INSTEK GSP-930 (9 kHz – 3 GHz).
- 9.5 Oscilloscopes:
  - 9.5.1 4-channel mixed signal oscilloscope Yokogawa DLM2034 (350 MHz).
  - 9.5.2 4/8-channel USB oscilloscopes: PICO 3424, 4424, 6403, 4824.
- 9.6 Generators:
  - 9.6.1 Function generator Escort EGC-3235A.
  - 9.6.2 Function/arbitrary waveform generator Agilent 33220A.
  - 9.6.3 2-channel function/arbitrary waveform generator Rigol DG1032Z.
  - 9.6.4 4-channel function generator Tabor WW5064.
- 9.7 Amplifiers:
  - 9.7.1 Piezo amplifier Piezo Systems EPA-104 (DC – 0.3 MHz, 40 W).
  - 9.7.2 High-power piezo amplifier Lab Systems A-310 (DC – 0.3 MHz, 250 W).
  - 9.7.3 3-channel piezo amplifier Piezomechanik SVR-150-3 (-30 – 150 V, 60 mA, 10 kHz).
  - 9.7.4 Wideband power amplifier Krohn-Hite 7500 with impedance matching transformer MT56R (DC – 1 MHz, 75 W).
  - 9.7.5 High-frequency high-current amplifier Newtons4th LPA05 (DC – 1 MHz, 90 VA).
  - 9.7.6 Wideband amplifier Newtons4th LPA01 (DC – 1 MHz).
  - 9.7.7 Power amplifier FLC Electronics P200 (input: 10 V, output: 100 V, 1 A, 80 kHz).
  - 9.7.8 4-channel signal conditioner Measurement Specialties 161A (for piezoelectric transducers).

## 9.8 Power supplies:

9.8.1 3-channel Rigol DP831A (160 W).

9.8.2 3-channel Keithley 2230-30-1 (120 W).

## 9.9 Programmable amplifier AIM TTI EX355P

## 9.10 Data acquisition:

9.10.1 High-performance reconfigurable NI system 781787-02 for embedded monitoring and control of analog signals (CRIO-9082, 8-Slot, LX150, RT).

9.10.2 Data acquisition system ALMEMO 5690-2M09BT8.

9.11 Electric and magnetic field analyzer EHP-50D by Narda Safety Test Solutions.

9.12 3-axis magnetometer Lake Shore 460 with sensor probe MMZ-2508-UH.

9.13 Single-axis magnetometer Magnet-Physik FH-54.

9.14 Portable multifunctional environment meter Velleman DVM401 (noise, temperature, humidity, illuminance measurements).

9.15 Acoustic noise measurement instrument VT-400.

9.16 Portable 2-channel acoustic emission measurement unit MISTRAS Pocket AE-2.

9.17 Portable digital tachometer/stroboscope tester Lutron DT-2259 (tachometer: 5 – 100 000 RPM, stroboscope: 100 – 100 000 FPM/RPM).

9.18 Piezoelectric coefficient (d33, d31) quasi-static meter (Berlincourt method) PolyK PKD3-2000-F10N.

## 10. Miscellaneous

10.1 1000 ltr. environmental chamber JTH-1000Z with humidity & temperature control (-5...+150°C).

10.2 General-purpose vacuum chamber.

10.3 Solder fume extraction cabinet with filtering BOFA V250 with FumeCAB.

10.4 A setup for research/demonstration of lumped-parameter dynamical systems DSS-01.

10.5 PCB etching tank (transparent plastic) Gie-Tec EA141032K (1.25 ltr., 100 W).