Chosen aspects of biomechanical research

Speaker:

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25.04.2023

Presentation agenda:

1) Presentation of the Institute of Mechanics and Machine Design
   (Mechanical Engineering and Ship Technology Faculty,
   Gdansk University of Technology)

2) Research facilities (Laboratory of Mechanics of Materials and Structures,
   Laboratory of Biomechanics)

3) Mechanical study of „lattice structure" materials

4) Clinical study and biomechanical study of patients with muscular dystrophy

Introduction: Cooperation with Lodz University of Technology

- OPUS 9 No.2015/17/B/ST8/01700, 2016-2018; Supervisor: Prof. Jan Awrejcewicz

- Conferences “Dynamical Systems - Theory and Application”

- Ludwicki M., Zagrodny B., Wojnicz W., Mrozowski J., Awrejcewicz J., ***Influence of additional loads on chosen gait parameters and muscles activity***, Vibrations in Physical Systems (VIBSYS 2016), vol. XXVII, eds. Cempel C., Dobry M.W., Stręk T., Poznan, **2016**, p. 227-236

- Wojnicz W., Zagrodny B., Ludwicki M., Awrejcewicz J., Wittbrodt E., ***A two-dimensional approach for modelling of pennate muscle behaviour***. Biocybernetics and Biomedical Engineering 37, **2017**, p. 302-315

- Zagrodny B., Ludwicki M., Wojnicz W., Mrozowski J., Awrejcewicz J., ***Cooperation of mono- and bi-articular muscles: human lower limb***. Journal of Musculoskeletal and Neuronal Interactions, **2018**, p.1-7

- Wojnicz W., Zagrodny B., Ludwicki M., Syczewska M., J. Mrozowski, Awrejcewicz J., ***Approach for determination of functioning of lower limb muscles***. Dynamical Systems in Applications (ed. J. Awrejcewicz). Springer Proceedings in Mathematics & Statistics, Vol. 249, **2018**, p.423-38

- Wojnicz W., Zagrodny B., Ludwicki M., Mrozowski J., Awrejcewicz J., Wittbrodt E., ***Multibody models for gait analysis***. Applicable Solutions in non-linear dynamical systems, eds. Awrejcewicz J., Kaźmierczak M., Mrozowski J., Dynamical Systems - Theory and Application **2019**, Łódź, Wydawnictwo Politechniki Łódzkiej, ISBN 978-83-66287-30-3, p.523 – 538.

- Klepczyńska M., Zagrody B., Wojnicz W., Ludwicki M., J. Awrejcewicz, ***Influence of the shoe type on the ground reaction forces***. Theoretical Approaches in Non-Linear Dynamical Systems, eds. Awrejcewicz J., Kaźmierczak M., Mrozowski J., Dynamical Systems - Theory and Application **2019**, Łódź, Wydawnictwo Politechniki Łódzkiej, ISBN 978-83-66287-29-7, p.253 – 268

- Zagrodny B., Wojnicz W., Ludwicki M., Awrejcewicz J., ***Could thermal imaging supplement surface electromyography measurements for skeletal muscles?***, IEEE Transactions on Instrumentation & Measurement, **2020**, Print ISSN 0018-9456, Online ISSN 1557-9662, pp.1-10, DOI 10.1109/TIM.2020.3023216.

- Zagrodny B., Ludwicki M., Wojnicz W., ***The influence of external additional loading on the muscle activity and ground reaction forces during gait, research article***, Applied Bionics and Biomechanics, Volume **2021**, Article ID 5532012, p.1-10, https://doi.org/10.1155/2021/5532012

- Wojnicz W., Zagrodny B., Ludwicki M.,Awrejcewicz J., ***Mathematical approach to assess a human gait***, Springer Proceedings in Mathematics & Statistics, 'Perspectives in Dynamical Systems I: Mechatronics and Life Sciences', Springer, pp.79-93, **2022**, https://doi.org/10.1007/978-3-030-77306-9_8

- Wojnicz W., Sobierajska-Rek A., Zagrodny B., Ludwicki M., Jabłońska-Brudło J., Forysiak K., ***A new approach to assess quality of motion in functional task of upper limb in Duchenne muscular dystrophy***. Appl. Sci. **2022**, 12, 12247. https://doi.org/10.3390/app122312247

Topics of the published joint papers are related to:

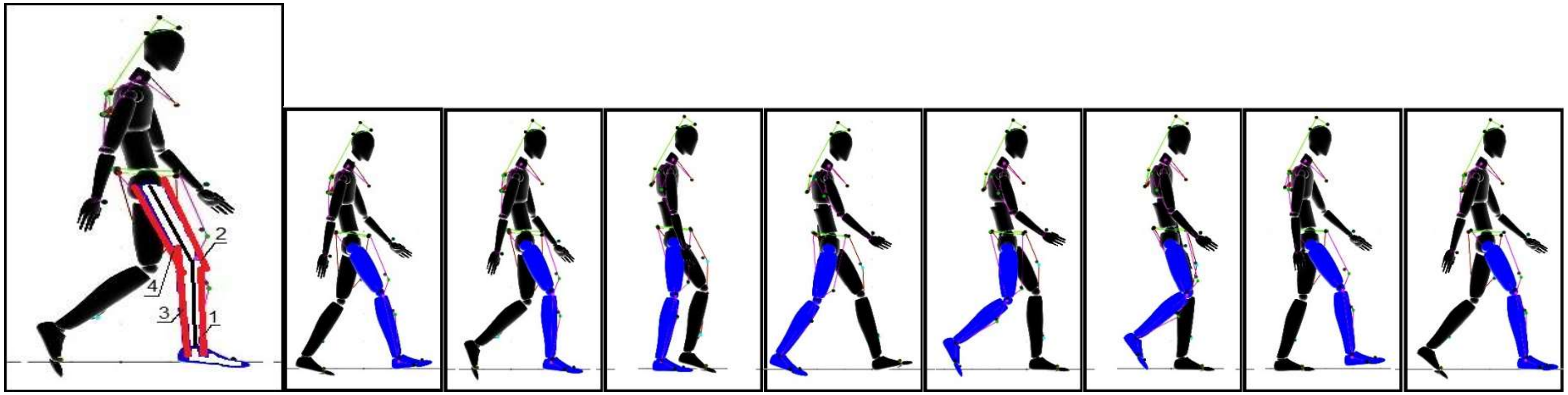
1) **Musculo-Skeletal Modelling (new rheological models of straited skeletal muscle functioning)**

2) **Assessment of parameters of the human gait by using**

Motion Capture System + Thermal analysis

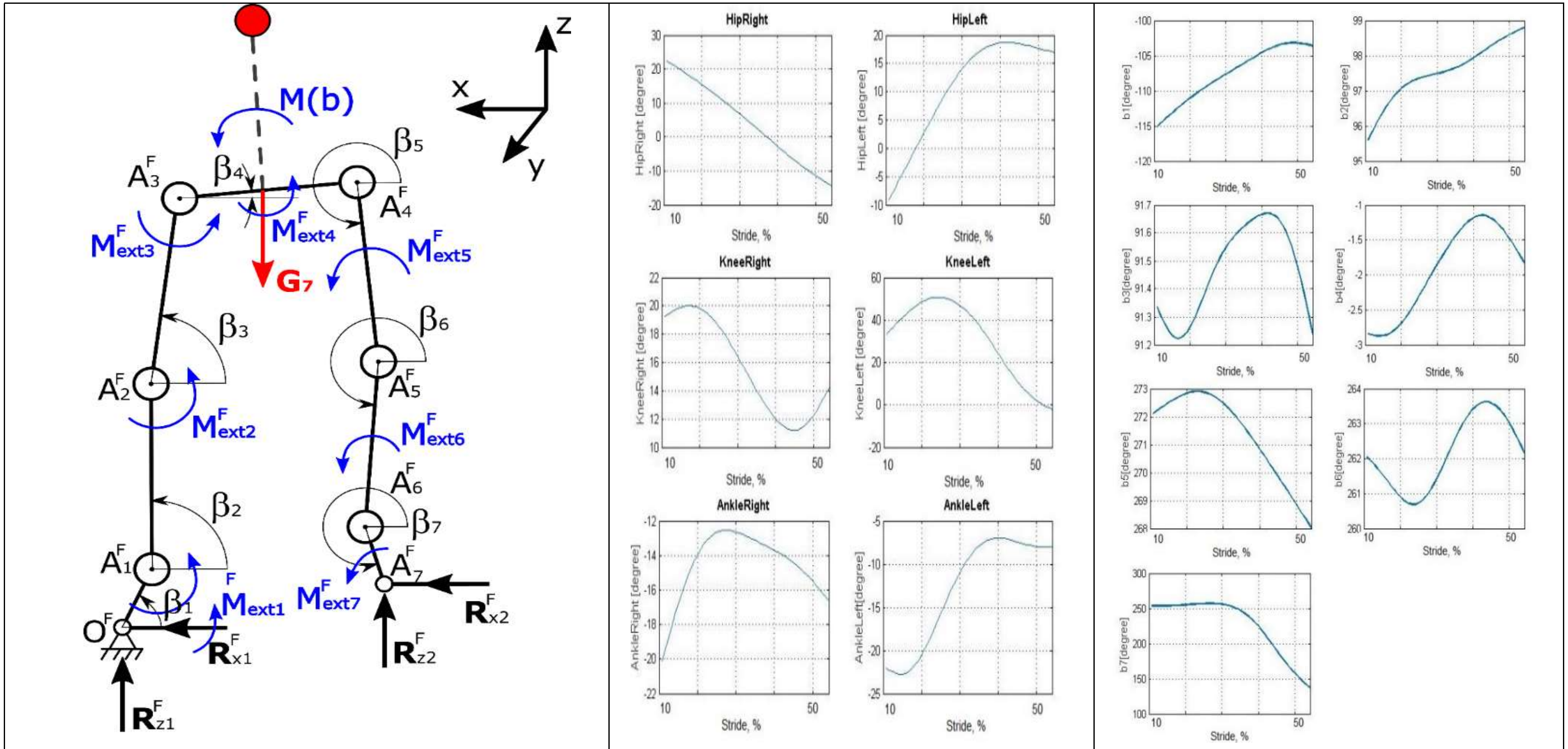
Motion Capture System + Force plate

Motion Capture System+ Force plate + surface EMG



***Wojnicz W., Zagrodny B., Ludwicki M., Syczewska M., J. Mrozowski, Awrejcewicz J.**, Approach for determination of functioning of lower limb muscles. Dynamical Systems in Applications (ed. J. Awrejcewicz). Springer Proceedings in Mathematics & Statistics, Vol. 249, **2018**, s.423-38*

3) Modelling of the human gait (multibody approach) by using Motion Capture System + Force plate + surface EMG



Kinematic data (sagittal plane) Kinematic data (frontal plane)

Wojnicz W., Zagrodny B., Ludwicki M., Mrozowski J., Awrejcewicz J., Wittbrodt E., *Multibody models for gait analysis. Applicable Solutions in non-linear dynamical systems,eds. Awrejcewicz J., Kaźmierczak M., Mrozowski J., Dynamical Systems - Theory and Application* ***2019****, Lodz, Wydawnictwo Politechniki Łódzkiej, p.523 –528*

4) Assessment of the human activities of healthy adults/teenagers by using Motion Capture System + Thermal analysis + surface EMG

5) Assessment of the human activities of patients with muscular dystrophy by using Motion Capture System + surface EMG

GDAŃSK UNIVERSITY OF TECHNOLOGY

RESEARCH UNIVERSITY
EXCELLENCE INITIATIVE
Ministry of Science and Higher Education

Part 1. The Institute of Mechanics and Machine Design

Mechanical Engineering and Ship Technology Faculty

Gdansk University of Technology

Statute

Fahrenheit Universities

PRELIMINARY PROVISIONS

Article 1

1. The Fahrenheit Union of Universities in Gdańsk, hereinafter referred to as the "Union", is a union of Gdańsk public higher education institutions pursuant to Article 28 of the Law on Higher Education Act of 27 July 2005 (the consolidated text in the Journal of Laws of 2017, item 2183, as amended) applied to this Union on the basis of Article 203 para. 3 of the Act of 3 July 2018 – The regulations enacting the Law on Higher Education and Science Act (Journal of Laws 2018, item 1669).
2. The Union shall comprise: the Medical University of Gdańsk, hereinafter the "MUG", the Gdańsk University of Technology, hereinafter the "Gdańsk Tech", and the University of Gdańsk, hereinafter the "UG", all of them hereinafter referred to as the participating universities.
3. The participating universities shall be independent with regard to their previous activity and remain autonomous in all the areas of their activities.

Faculties

Faculties of Gdańsk University of Technology (Gdańsk Tech)

FACULTY OF ARCHITECTURE

FACULTY OF APPLIED PHYSICS AND MATHEMATICS

FACULTY OF CHEMISTRY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

FACULTY OF ELECTRICAL AND CONTROL ENGINEERING

FACULTY OF MECHANICAL ENGINEERING AND SHIP TECHNOLOGY

FACULTY OF ELECTRONICS, TELECOMMUNICATIONS AND INFORMATICS

FACULTY OF MANAGEMENT AND ECONOMICS

GDAŃSK UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND SHIP TECHNOLOGY

Authorites

Dean of Faculty

Prof. PhD, DSc, Eng. Andrzej Seweryn

Vice-Dean for Research

Prof. PhD, DSc, Eng. Michał Wasilczuk

Vice-Dean for Cooperation

PhD, DSc, Eng. Mariusz Deja, Gdańsk Tech professor

Vice-Dean for Development

PhD, DSc, Eng. Jacek Kropiwnicki, Gdańsk Tech professor

Vice-Dean for Education

PhD Eng. Aleksandra Teresa Wiśniewska

Vice-Dean for Student Affairs

PhD Eng. Roman Liberacki

Academic Staff: 196

Institutes

Institute of Energy

Institute of Mechanics and Machine Design

Institute of Ocean Engineering and Ship Technology

Institute of Manufacturing and Materials Technology

Institutes were established in January 2021

GDAŃSK UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND SHIP TECHNOLOGY

Sections

Within **Institute of Mechanics and Machine Design** operate following **Sections**:

- **Applied Mechanics and Biomechanics** Section
  The Head - **Wiktoria Wojnicz**, DSc Ph.D., Mech.Eng.
- **Hydraulics and Pneumatics** Section
  The Head - **Paweł Śliwiński**, DSc Ph.D., Mech.Eng.
- **Machine Design and Medical Engineering** Section
  The Head - **Michał Wasilczuk**, Prof., DSc Ph.D., Mech.Eng.
- **Mechanical Vehicles and Military Techniques** Section
  The Head - **Grzegorz Ronowski**, DSc Ph.D., Mech.Eng.
- **Mechatronics** Section
  The Head - **Marek Galewski**, DSc Ph.D., Mech,Eng.

Academic staff – 46 teachers

https://wimio.pg.edu.pl/en/imikm-en/sections

Institute of Mechanics and Machine Design

Machine Design and Medical Engineering Section

https://wimio.pg.edu.pl/en/imikm-en/section-mdme/staff-members-machine-design-and-medical-engineering-section

Michał Wasilczuk (Head of the Section):

- hydrodynamic bearings (especially thrust bearings)
- unusual bearing materials, coatings and lubricants, rolling bearings, diagnostics and machine design

Szymon Grymek:

- designing medical and rehabilitation devices
- anastomosis of soft tissues
- pneumatic driving systems
- methods of artificial intelligence in design

Waldemar Karaszewski:

- rPET regranulate on the axial and pressure strength of packaging made of preforms by blowing process
- analysis of the parameters of the technological process for the production of PET packaging by blowing process in order to reduce the consumption of electricity and compressed air

Jacek Łubiński:

- tribology and bearing engineering

Janusz Musiał:

- surface layer of rolling and sliding bearings
- geometric structure of the surface of machine parts

Artur Olszewski:

- tribology and bearing engineering

Michał Wodtke:

- investigations (experimental and theoretical) of bearing systems (hydrodynamic, hydrostatic, journal, thrust) oil lubricated and also with the use of unusual lubricants (water, MR fluids), acoustic levitation
- advanced analysis of mechanical systems with the use of numerical methods

Institute of Mechanics and Machine Design

Mechanical Vehicles and Military Techniques Section

https://wimio.pg.edu.pl/en/imikm-en/section-mvmt/staff-members

Grzegorz Ronowski (Head of the Section) :

- testing the rolling resistance of tires and surfaces in road and laboratory conditions

Jerzy Ejsmont:

- car tire testing
- weapons and ballistics
- neutralization of explosion hazards

Mirosław Gerigk:

- structural and strength analysis of unmanned AUVs, unsinkability of ro-ro ships in a damaged condition

Piotr Mioduszewski:

- noise of car tires
- noisiness of road surfaces (quiet surfaces)
- development of methods for measuring the noise of car tires and the noisiness of road surfaces
- traffic noise

Institute of Mechanics and Machine Design

Mechatronics Section

https://wimio.pg.edu.pl/en/imikm-en/section-m/staff-members

Marek Galewski (Head of the Section):

- vibration reduction in milling and turning operations
- vibration measurement systems (including integration and software development)
- applications of Swarm Intelligence in identification and system control

Krzysztof Kaliński:

- applied mechanics, Machine dynamics, Finite element method, Modal analysis
- mechatronics, Optimal control, Supervision of dynamic processes
- dynamics of machine tools and machining processes, incl. vibration reduction during milling and turning

Hydraulics and Pneumatics Section

https://wimio.pg.edu.pl/en/imikm-en/section-hp/staff-members

Paweł Śliwiński (Head of the Section):

- design and development research of pumps, hydraulic motors and valves
- tests of hydraulic drives
- designing hydraulic drives
- design of satellite working mechanisms

Ryszard Jasiński:

- testing of hydraulic components and systems in various environmental conditions, also in thermal shock conditions.
- design and testing of pneumatic, hydraulic components and systems
- design and testing of pneumatic, hydraulic and mechatronic components and systems for medical devices

Institute of Mechanics and Machine Design

Applied Mechanics and Biomechanics Section

https://wimio.pg.edu.pl/en/imikm-en/section-amb

Wiktoria Wojnicz (Head of the Section):

- biomechanical analysis of musculoskeletal system by using surface electromyography and motion capture (cooperation with Lodz University of Technology)
- mechanical testing of materials, biological tissues, artificial tissues and lattice structures (Zwick/Roell testing machines)
- design of rehabilitation devices on the base of motor control analysis
- multibody systems, finite element method (Abaqus)

Marek Krawczuk:

- damage detection in constructional elements and structures
- numerical methods in mechanics
- smart materials for control of structural dynamic

Janusz Siebert:

- problems in medicine

Edmund Wittbrodt:

- dynamic modelling, analysis and control of complex mechanical, mechatronic and biomechanical systems
- court expert of the District Court in Gdansk in the field of testing materials and strength of materials as well as construction and operation of machines

Krzysztof Lipiński:

- dynamics of multibody systems
- theory of machines and mechanisms
- vibrations of linear systems
- numerical methods in mechanics

Oleksii Nosko:

- airborne particle emissions from sliding contacts
- neat conduction problems of sliding friction
- temperature measurements at sliding contacts

Jarosław Szwedowicz:

- damping technologies, FSI, ASI preventing from HCF
- predictive Maintenance and wireless sensors
- additive Manufacturing and smart materials (SMA & PMs)

Wojciech Macek:

- fatigue of materials
- factography
- surface metrology

Institute of Mechanics and Machine Design

Part 2. Research facilities

Laboratory of Mechanics of Materials and Structures

Laboratory of Biomechanics

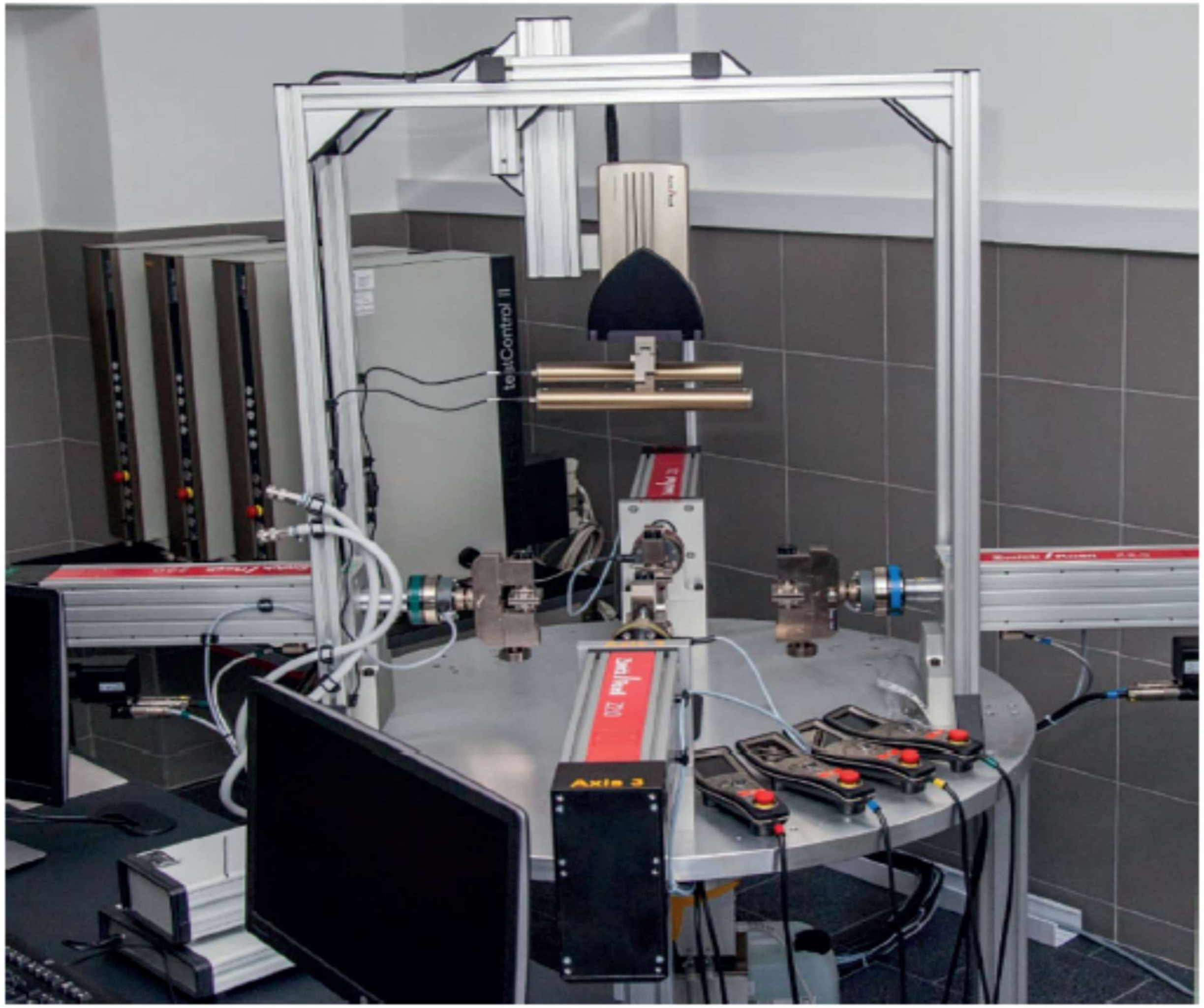
Zwick Biaxial Testing machine: *Zwick Biaxial 4 x EZ002 (4 x 2kN)*

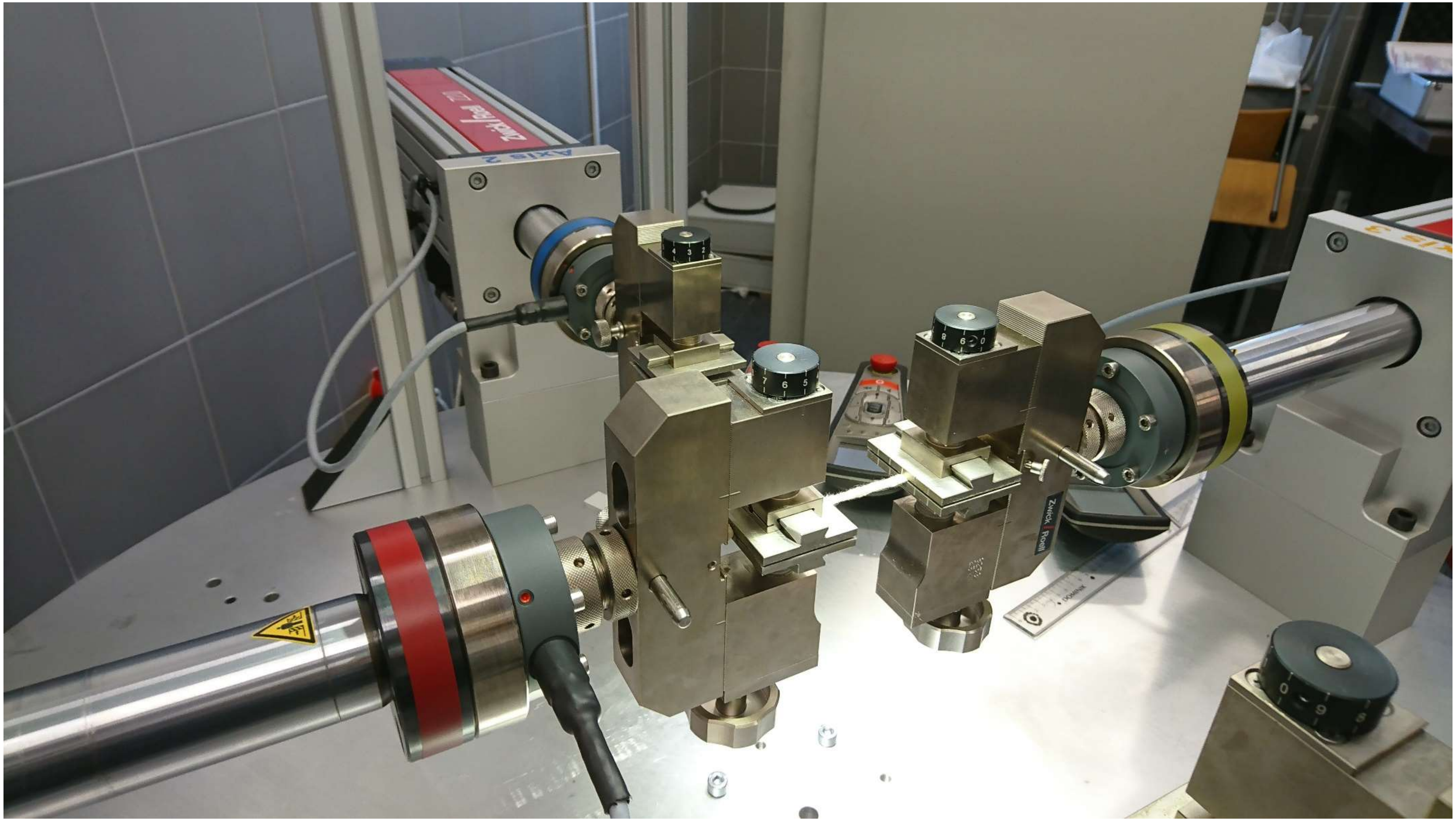
Range:

Static uniaxial and biaxial test (up to 2kN)

Cyclic uniaxial and biaxial test (up to 2kN and up to 1Hz)

Chamber with the temperature control [10; 40] C^0




Zwick Roell

Zwick LTM10/Z010TE

<table>
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1 Range:

Static uniaxial test (up to 10kN)

Torsion test (up to 20 Nm)

Complex load: Tensile – torsion test (up 5kN and 20Nm)

Cyclic uniaxial load (up to 10 kN and up to 1 Hz)

Complex cyclic load (up 5kN and 20Nm and up to 1 Hz)

Chamber with the temperature control [10; 40] C^0

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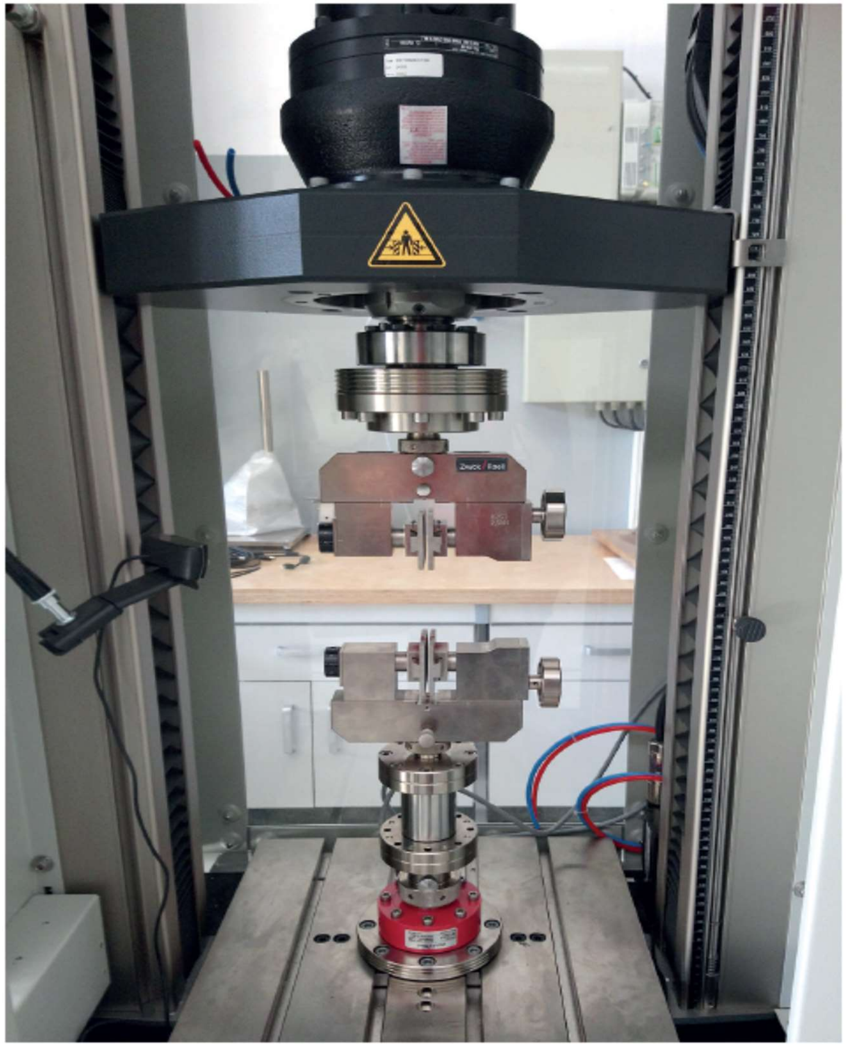

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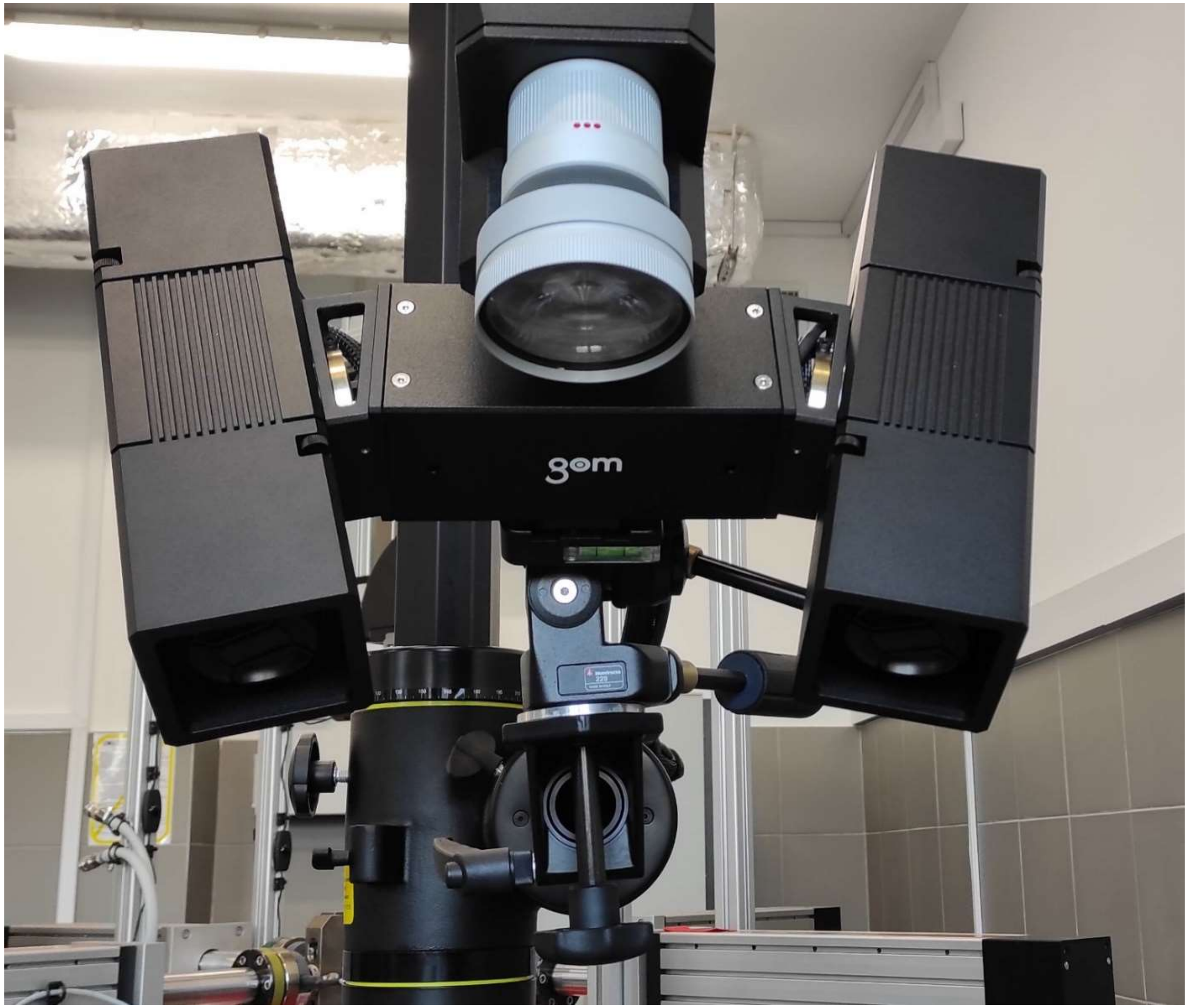
Zwick LTM10/Z010TE

2 Range: Static uniaxial test (up to 10kN) Cyclic uniaxial test (up to 10kN and up to 100Hz) Chamber with the temperature control [10; 40] C^0	

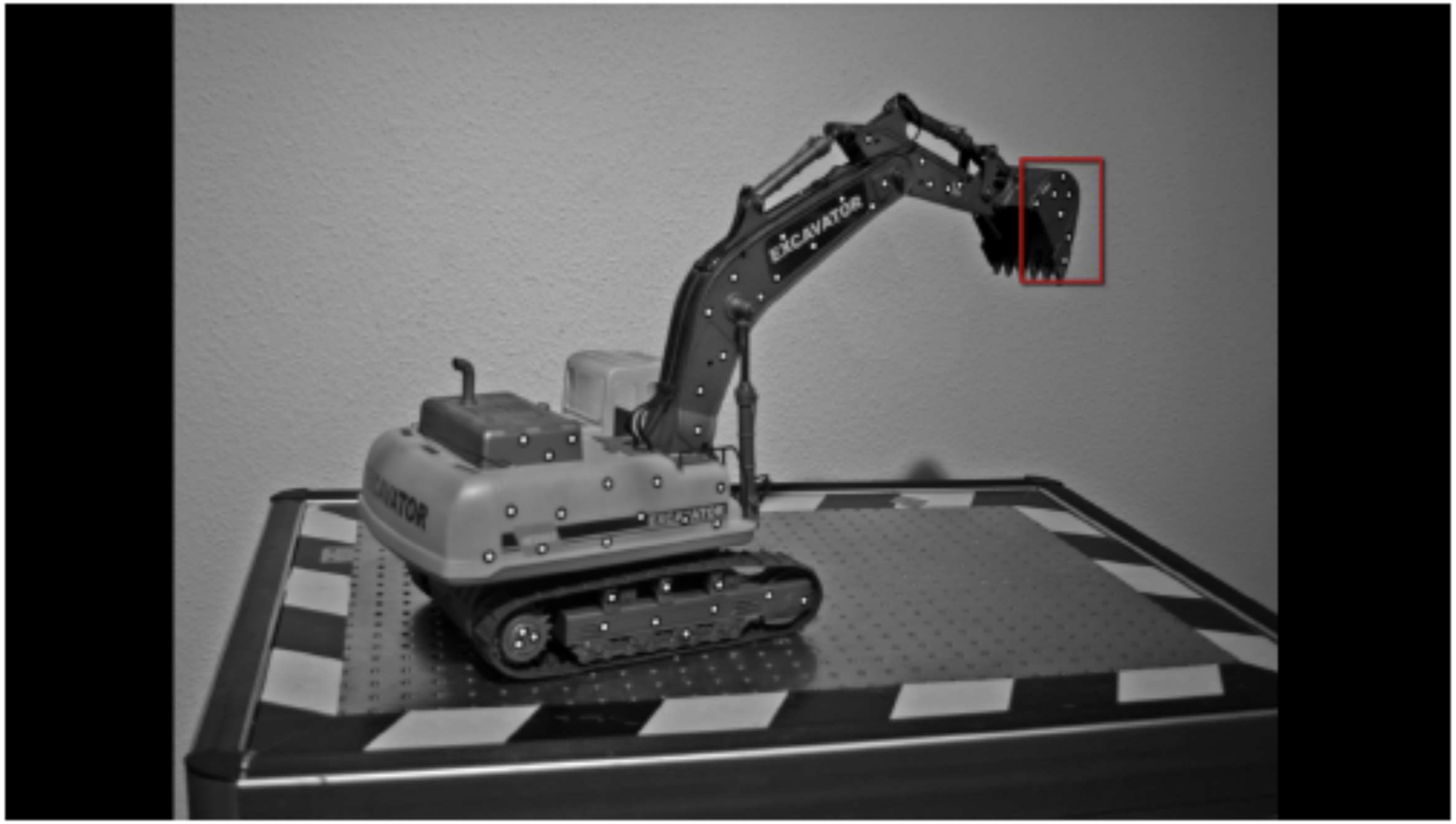
Equipment for testing:

- **hip endoprosthesis stems (ISO 7206-04, -06, -08, -10* and ASTM F2068)**
- **fiber composite materials by performing three point flexure test and four- point flexure test (ISO 14125, EN 2562, ASTM D7264)**
- **tibial plateaux of artificial knee joints (ASTM F1800, ISO 14879);**
- **metallic bone plates and fixation devices via four-point flexure test (ASTM F382, ISO 9585, ASTM F 1264 A1, A3, A4;**
- **spinal implants in a vertebrectomy model by performing static and dynamic tests (ASTM F1717);**
- **intervertebra disc prosthesis by performing quasistatic and oscillating tests (ASTM F2077);**
- **external skeletal fixation devices (ASTM F 1541);**
- **interconnection mechanisms and subassemblies used in spinal arthrodesis implants by performing static and fatigue tests (ASTM F1798).;**
- **metallic angled orthopedic fracture fixation devices (ASTM F384)**

ARAMIS SRX **(2022)**



ARAMIS SRX



Video 1: Tracking a reference point pattern over time

ARAMIS SRX

Video 2: Tracking a stochastic pattern over time

ARAMIS SRX

GOM/CP 40/ MV 560 mm

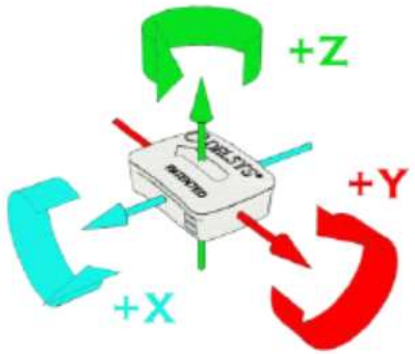
GOM/CP 40/ MV 170 mm

DELSYS SURFACE ELECTROMYOGRAPHY (2022)

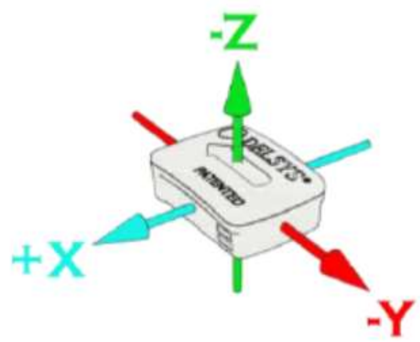
Trigno Avanti™ Sensor Features

Each Trigno Avanti™ Sensor is equipped with the following capabilities:

- onboard configurable precision EMG sensor
- built-in 9-axis inertial measurement unit (IMU)
- dual-mode "BLE-Base" communication
- onboard RMS and Mean calculations
- onboard orientation calculation
- onboard median frequency calculation
- software selectable operational modes
- inter-sensor latency < 1 sample period
- wireless transmission range 20+m[1]
- self-contained rechargeable battery
- battery charge monitoring and status indicator
- environmentally sealed enclosure
- low power mode
- auto shutoff
- internal magnetic switch
- LED User Feedback



Accelerometer + Gyroscope Axes

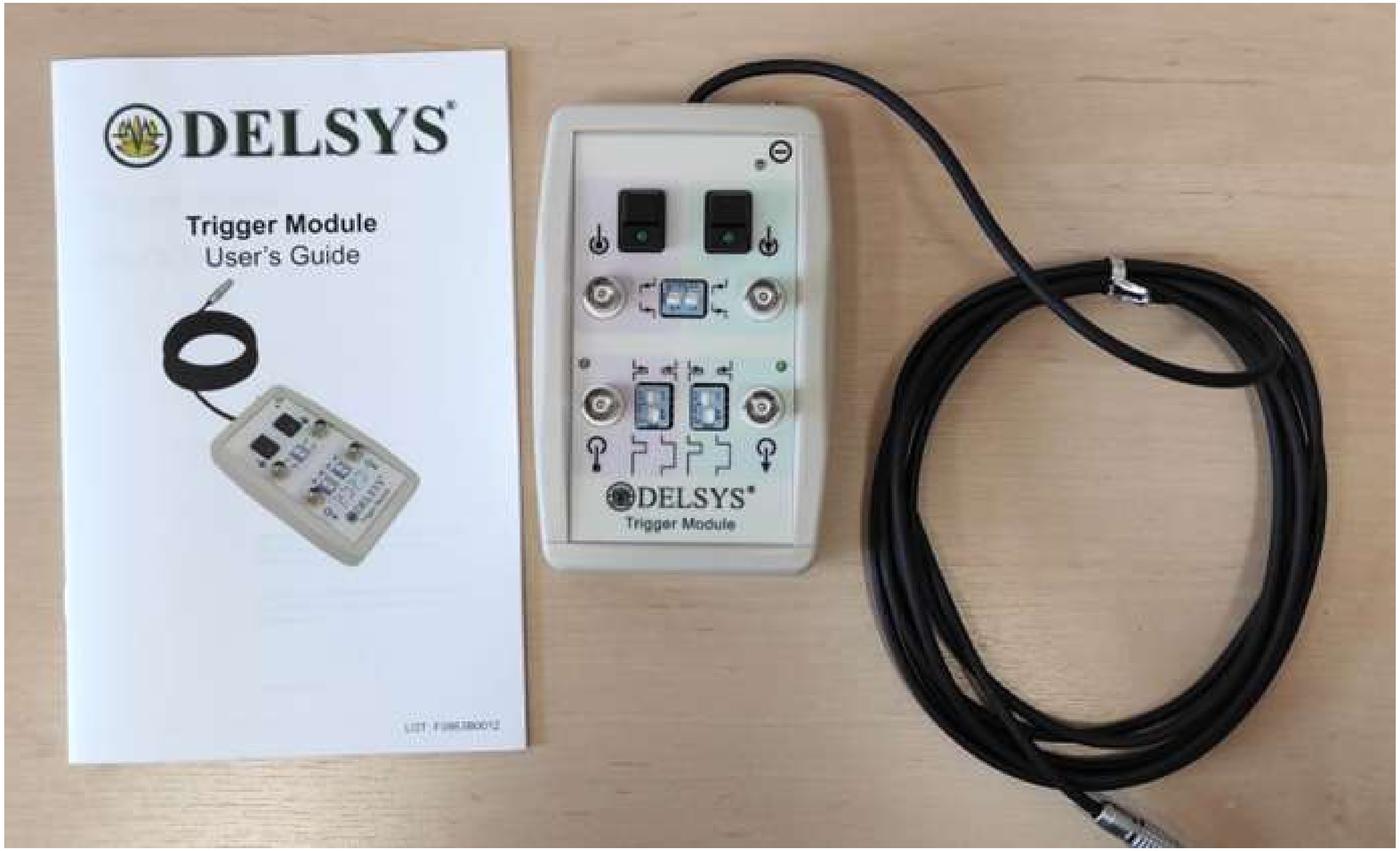


Magnetometer Axes

Reference Specifications

RF Frequency Band	2400-2483 MHz (ISM band)
Dimension	27 x 37 x 13 mm
Mass	14 g
Temperature Range[1]	5 - 45 degrees Celsius
EMG Signal Input Range	11mV / 22mV r.t.i.
EMG Signal Bandwidth	20-450 Hz / 10-850 Hz
EMG Contact Dimensions	5x1 mm
Contact Material[2]	99.9% silver
Accelerometer Range	±2g, ±4g, ±8g, ±16g
Accelerometer Bandwidth	24 Hz – 473Hz (configurable in software)
Gyroscope Range	±250 dps, ±500 dps. ±1000dps, ±2000dps
Gyroscope Bandwidth	24Hz – 360 Hz (configurable in software)
Magnetometer Range	±4900 uT
Magnetometer Bandwidth	50 Hz
Inter-Sensor Delay	< 1 sample period (Base Station only)
Intra-Channel Delay	< 1-2 sample period
Analog Output Range	± 5 V (Base Station only)
Analog Output Bandwidth[3] (Ch. X.1)	DC-500 Hz (Base Station Only)
Analog Output Bandwidth[3] (Ch. X.2, X.3, X.4)	DC-50 Hz (Base Station Only)

1) *Exposure beyond these temperature limits may damage the rechargeable battery.*
2) *Sensor skin contacts are made from pure silver and should not be used if allergic reactions to silver are expected or found to occur.*
3) *Refer to table 3 for the time-delays associated with analog outputs*


DELSYS
Trigger Module
User's Guide
DELSYS
Trigger Module

Part 3. Mechanical study of „lattice structure” materials

BIOCYBERNETICS AND BIOMEDICALENGINEERING 41 (2021) 667–678

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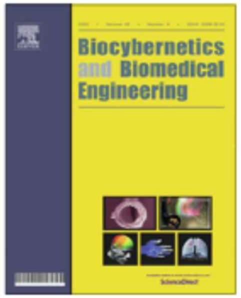


Original Research Article

Mathematical approach to design 3D scaffolds for the 3D printable bone implant

Wiktoria Wojnicz [a,*], *Marek Augustyniak* [b], *Piotr Borzyszkowski* [b]

[a] *Faculty of Mechanical Engineering and Ship Technology, Gdansk University of Technology, Gdansk, Poland*
[b] *Faculty of Applied Physics and Mathematics, Gdansk University of Technology, Gdansk, Poland*

The main motivation of this study was to create a new mathematical approach to design numerical models of 3D scaffold structures that can be used to produce 3D printable bone implants to reconstruct trabecular bone tissue deficiencies.

The aim of the study was to design numerical models of spatial scaffold structures (lattice materials) for the 3D printable bone implants.

The scope of this study involved numerical research by using FE method and experimental validation of proposed scaffolds produced by using a Fused Deposition Modeling (FMD) technology.

- The 3D numerical model of the human trabecular bone fragment were created and treated as a reference bone model.
- New nine 3D scaffold samples were designed and their numerical models were tested.
- Numerical research were conducted to assess physical properties of model of the reference bone sample and nine designed 3D scaffold samples.

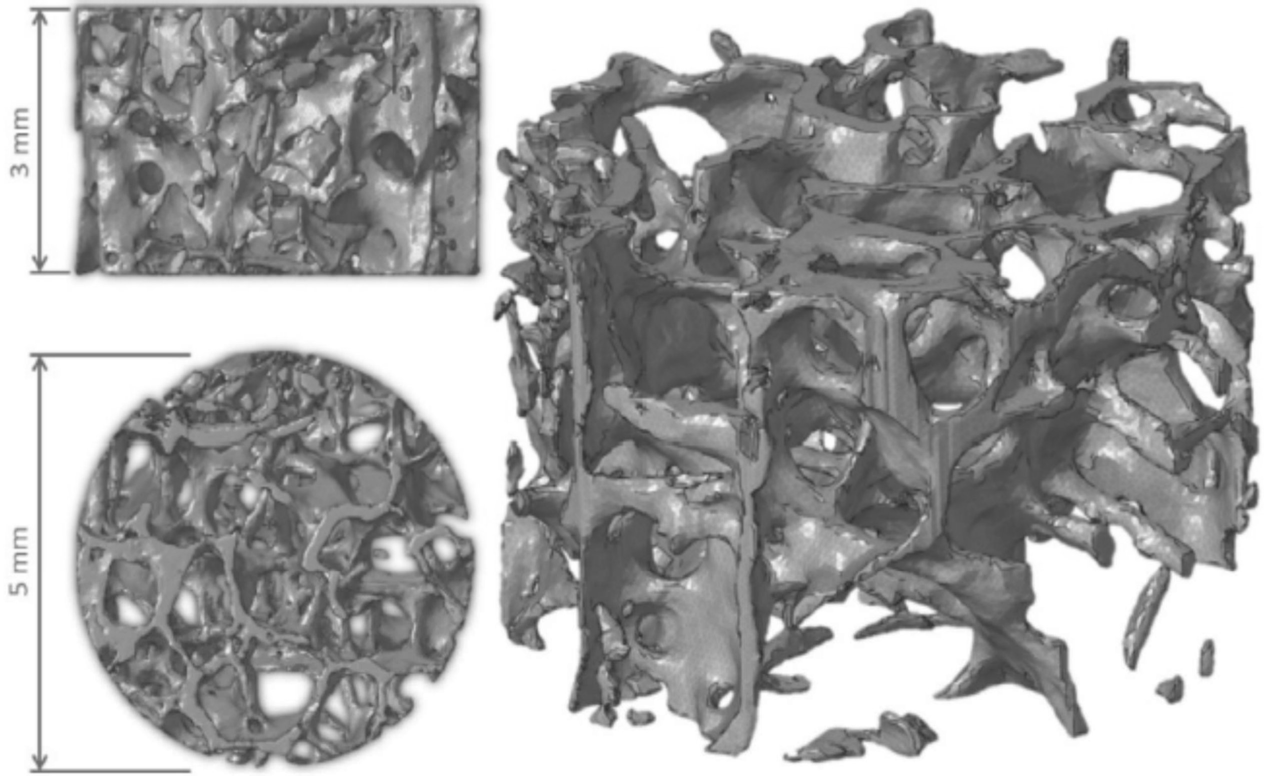


Fig. 1 – Numerical 3D model of lumbar vertebra fragment (reference bone sample).

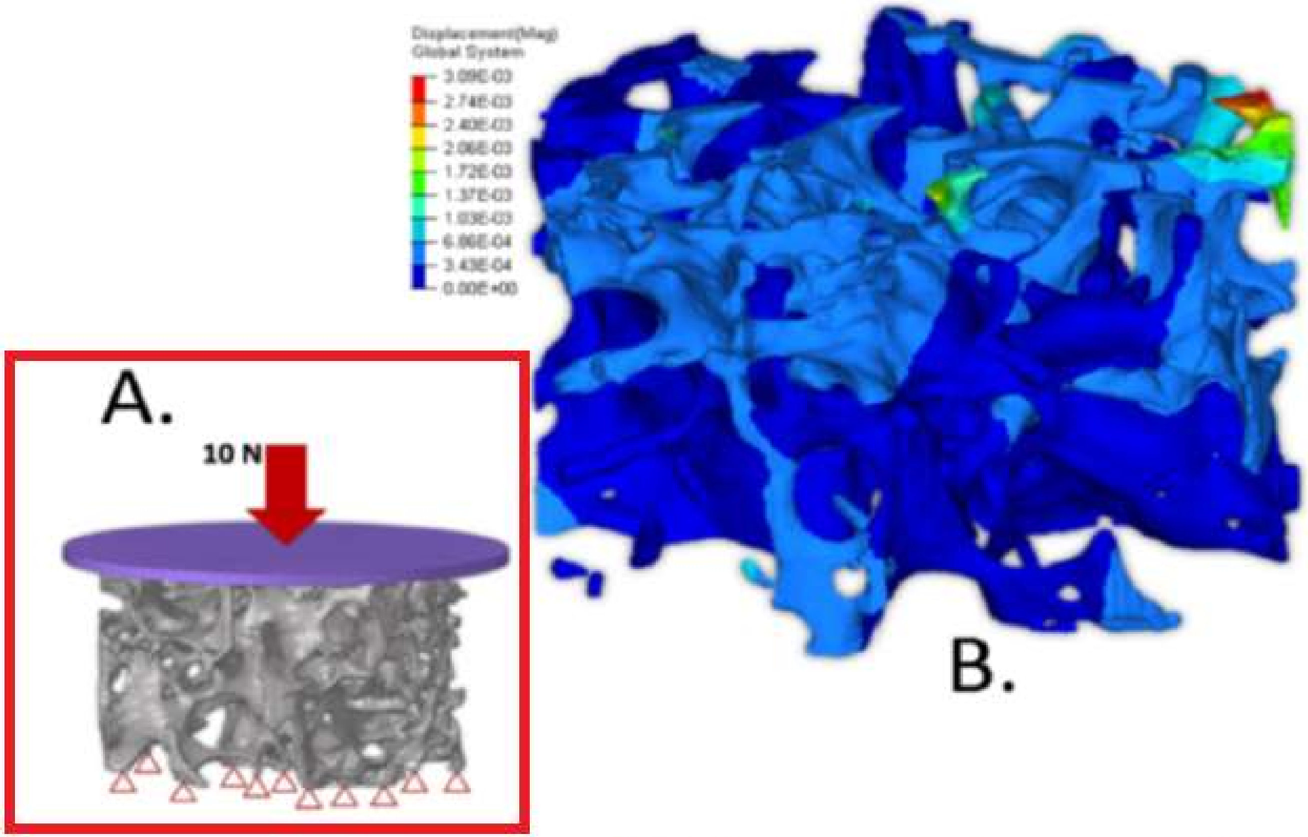
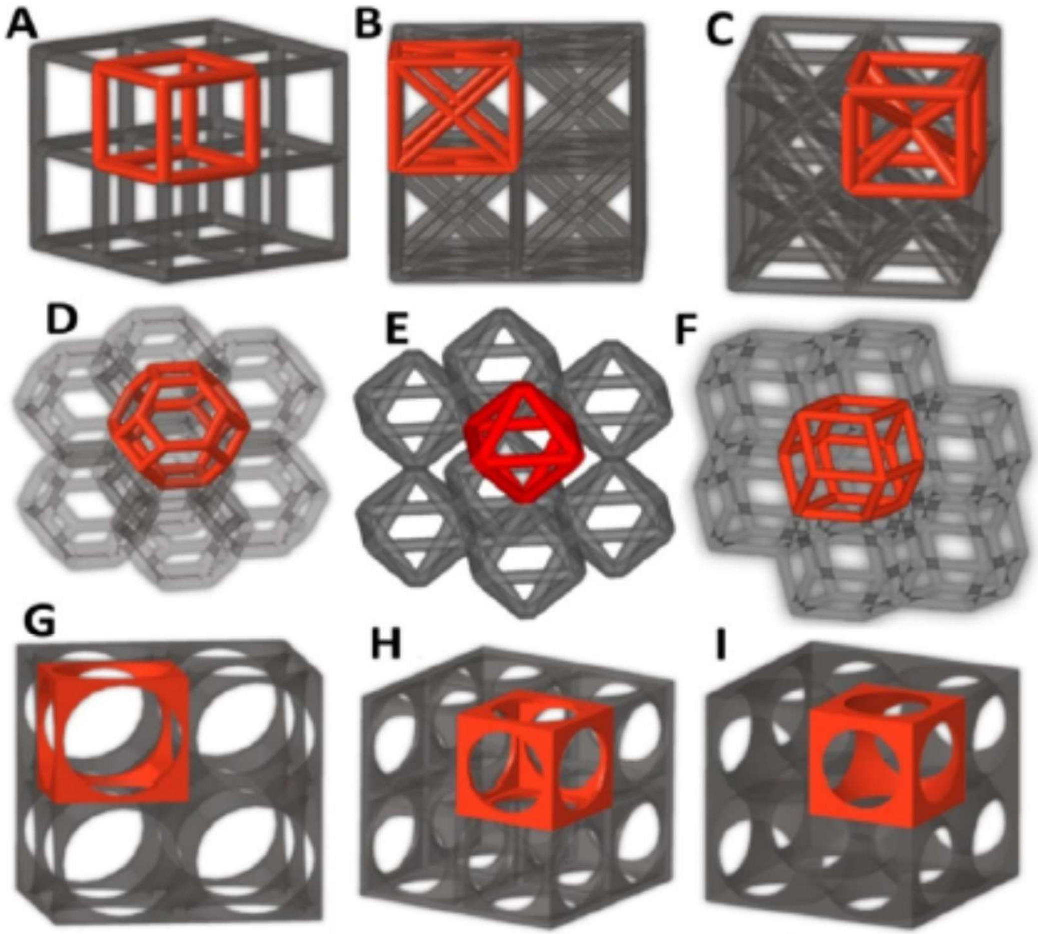


Fig. 2 – A) Numerical model of the reference bone sample in static compression numerical test; B) chosen results of vertical displacements.

New designed 3D scaffold units



A – regular cubic structure (A unit);

B – FCC structure (B unit);

C – BCC structure (C unit);

D – truncated octahedron structure (D unit);

E – octahedron structure (E unit);

F – rhombic dodecahedron structure (F unit);

G, H, I – subtractive structures (G unit, H unit and I unit).

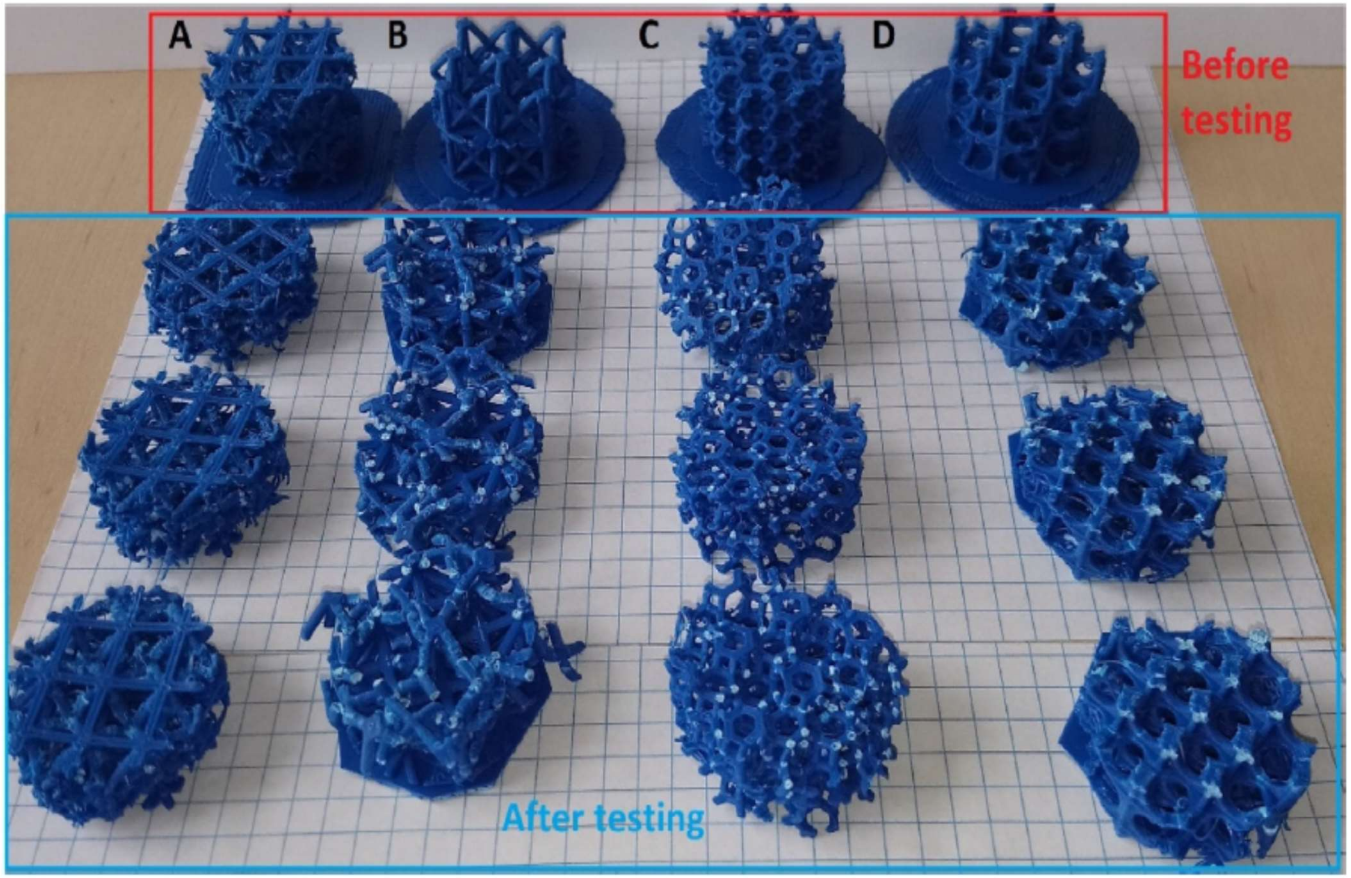


Fig. 7 – A) C unit (BCC structure); B) B unit (FCC structure); C) D unit (truncated octahedron structure); D) H unit (subtractive structure).

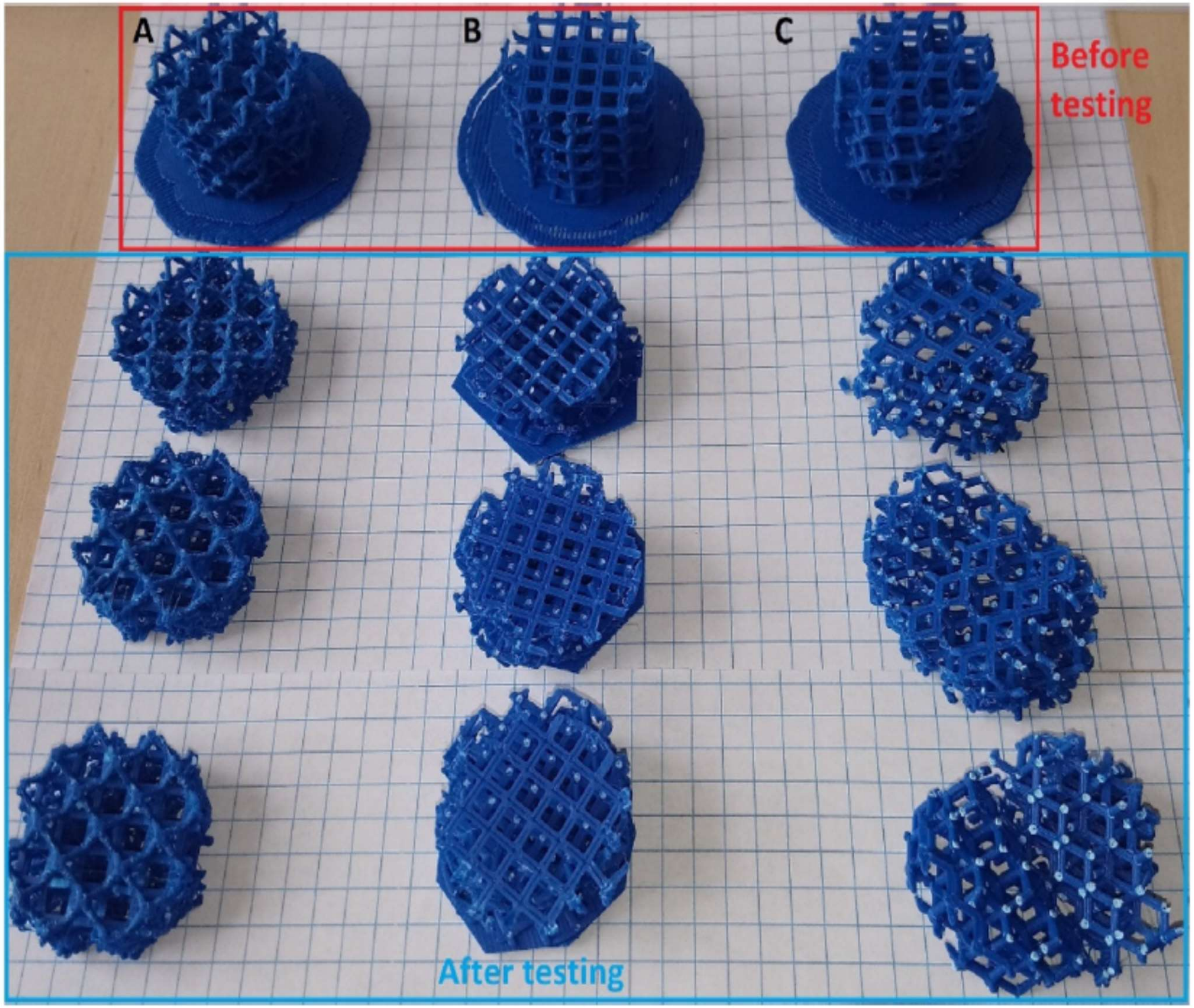


Fig. 8 – A) E unit (octahedron structure); B) A unit (regular cubic structure); C) F unit (rhombic dodecahedron structure).

Remark: technological problems (Zortrax 3D print)

Table 2 – FEM research summary of metrics of reference bone sample and new designed 3D scaffold samples.

Sample	Analysis Stage	Unit size [mm]	Relative density [%]	Surface area [mm^2]	E (Ti6-Al-4V) [GPa]	E (ABS) [GPa]
Reference bone unit	0	–	13.21	2.78	0.35	
A unit	3	0.84	12.44	2.85	5.85	0.17
B unit	3	1.77	15.35	2.85	4.64	0.14
C unit	3	1.45	14.56	2.78	2.91	0.09
D unit	3	1.04	13.73	2.89	1.61	0.05
E unit	3	0.79	11.07	2.87	1.66	0.05
F unit	3	1.12	14.04	2.85	1.57	0.05
G unit	3	1.10	12.53	2.00	3.56	0.10
H unit	3	1.10	13.99	2.84	5.87	0.19
I unit	3	0.82	11.12	2.85	6.08	0.18
F – optimized unit made of Ti-6Al-4V	4	1.12	7.50	2.05	0.33	–
H – optimized unit made of ABS	4	1.10	15.66	2.85	–	0.32

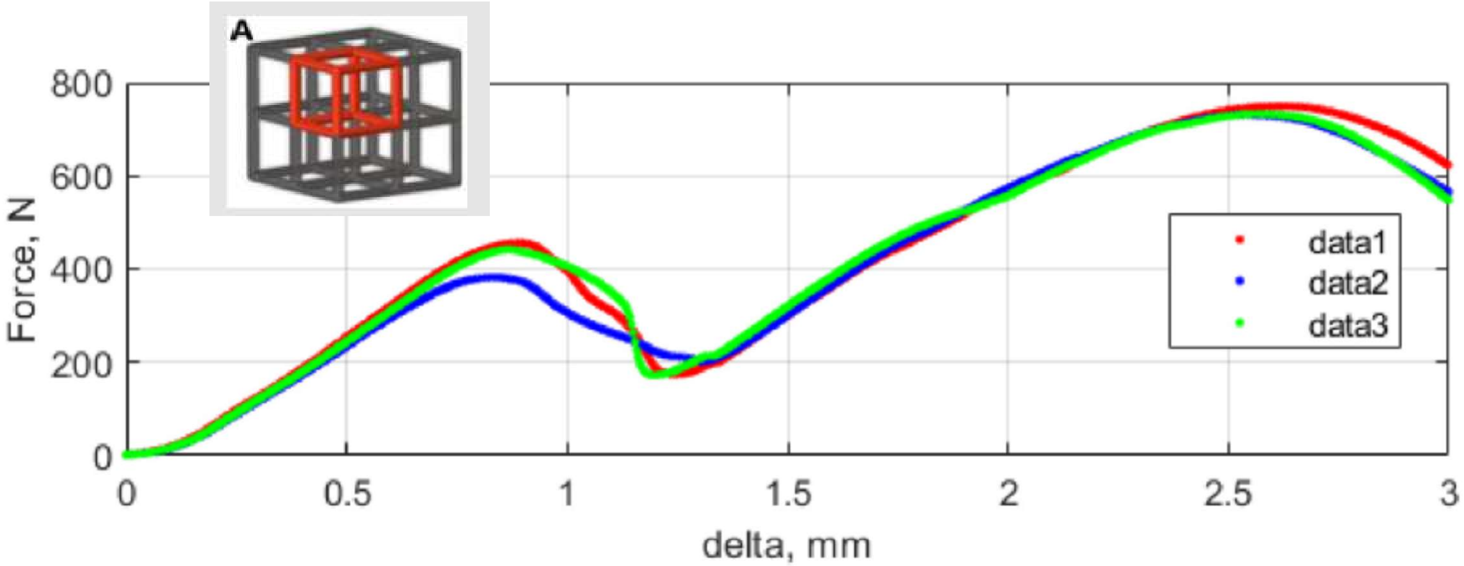


Fig. 9A – Force-displacement experimental relations of A unit (regular cubic structure).

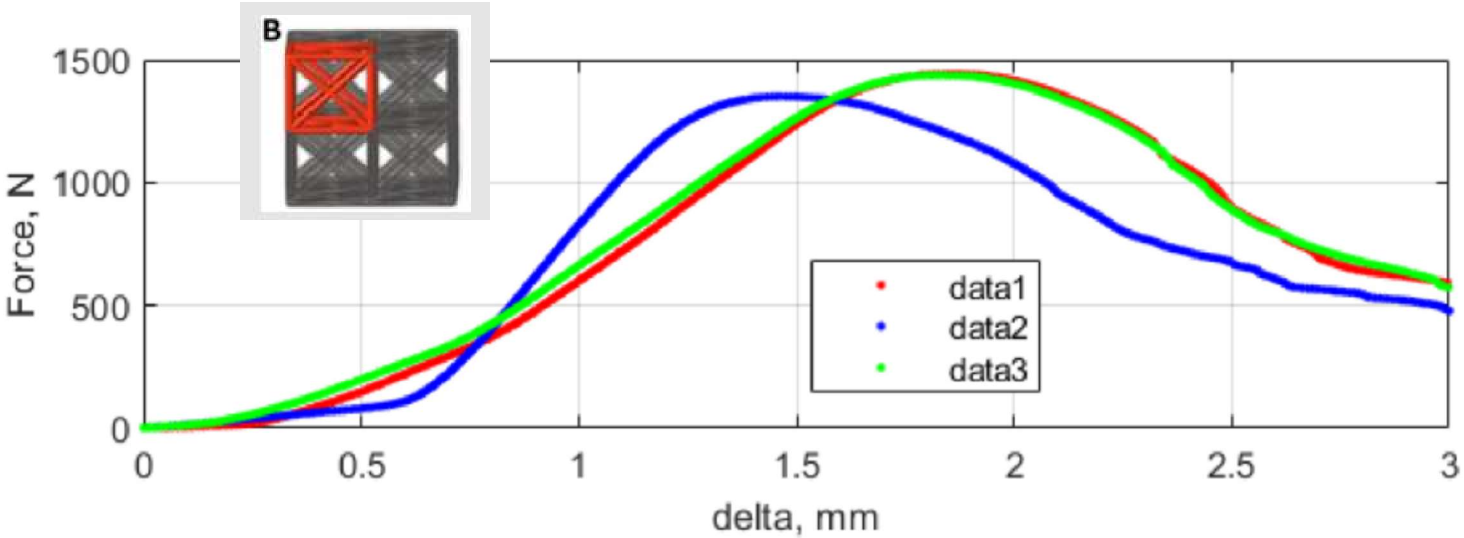


Fig. 9B – Force-displacement experimental relations of B unit (FCC structure).

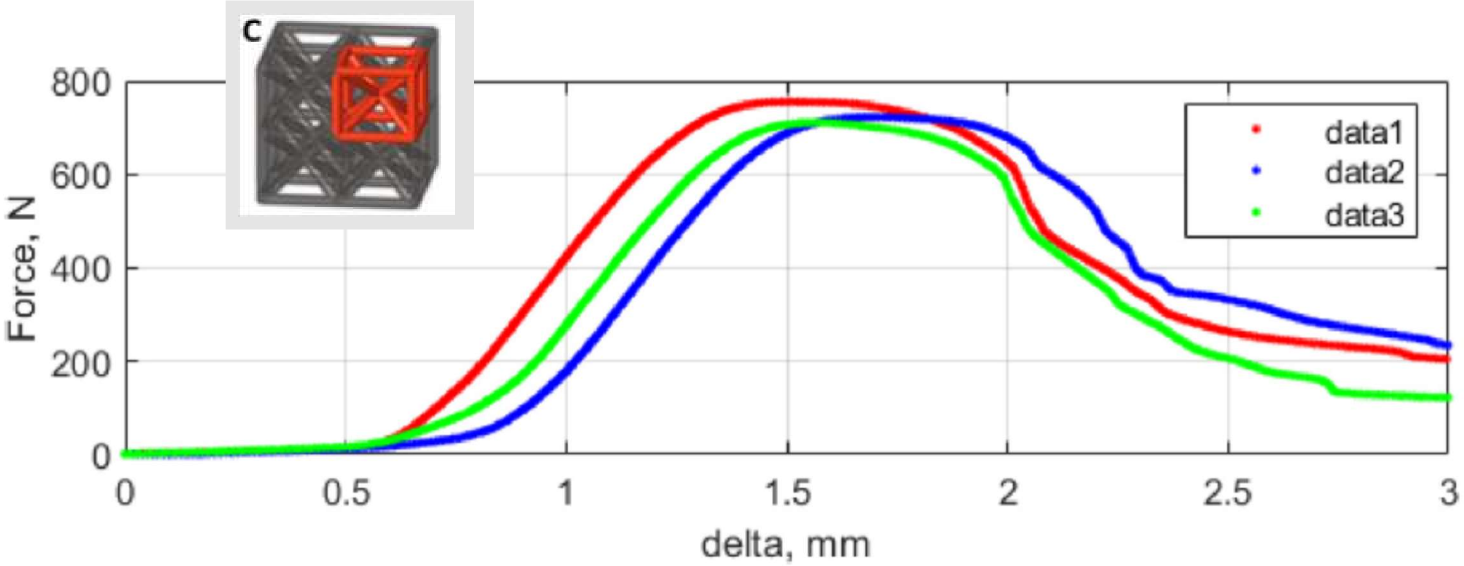


Fig. 9C – Force-displacement experimental relations of C unit (BCC structure).

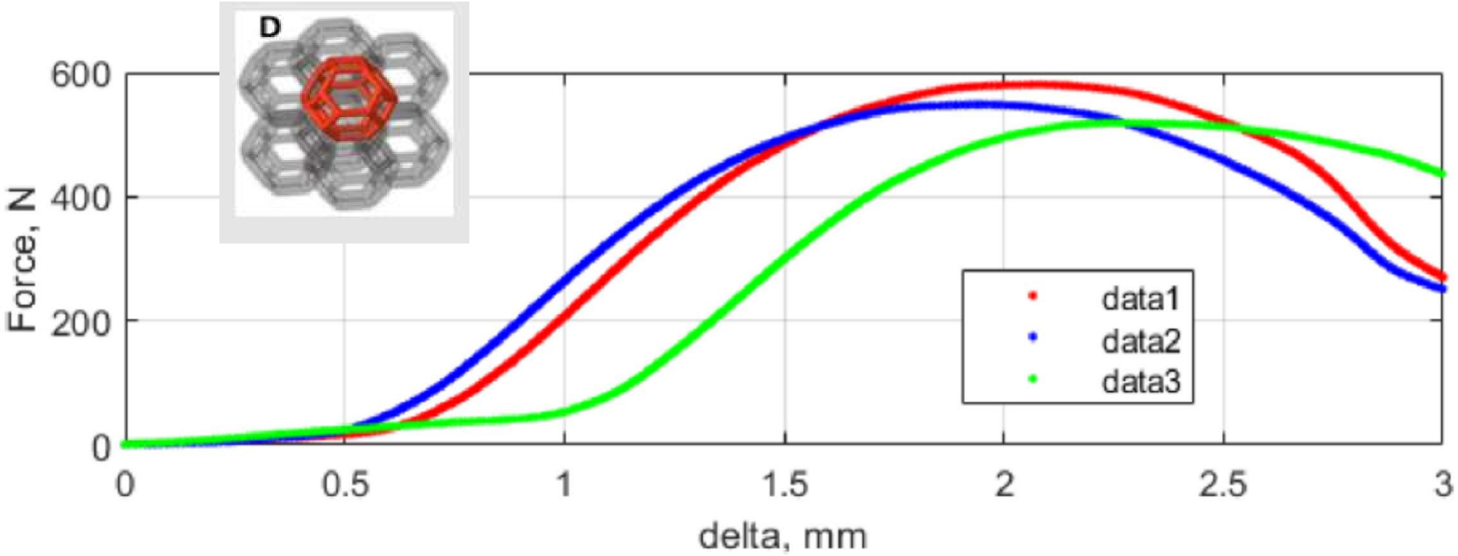


Fig. 9D – Force-displacement experimental relations of D unit (truncated octahedron structure).

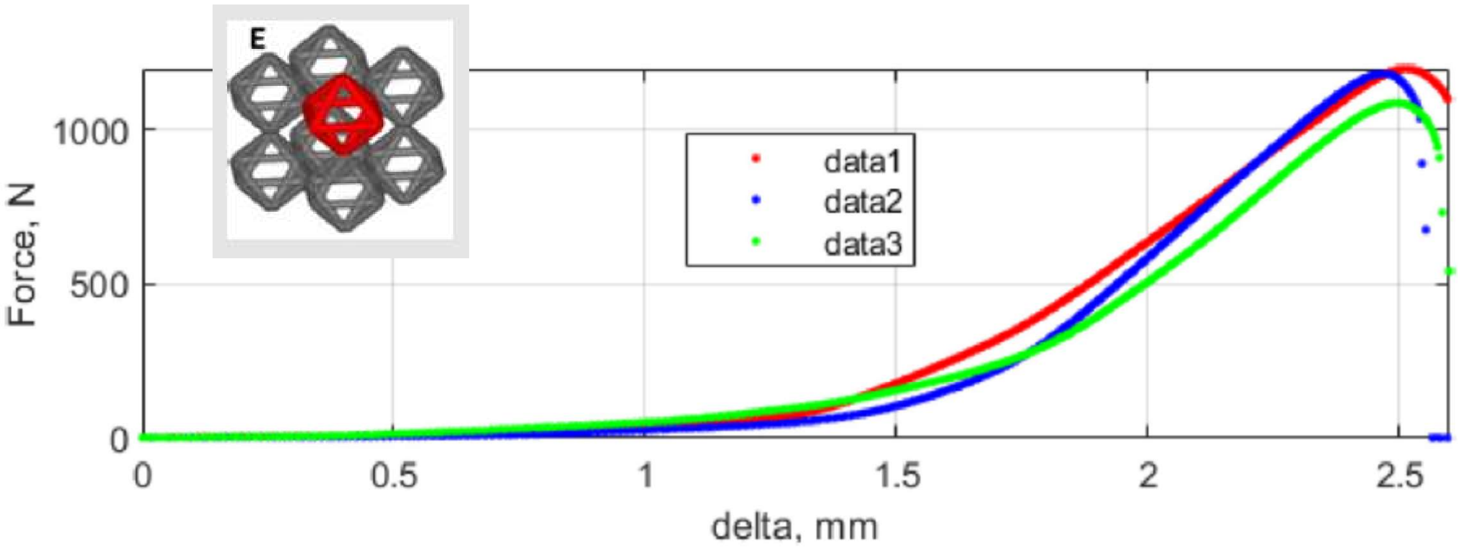


Fig. 9E – Force-displacement experimental relations of E unit (octahedron structure).

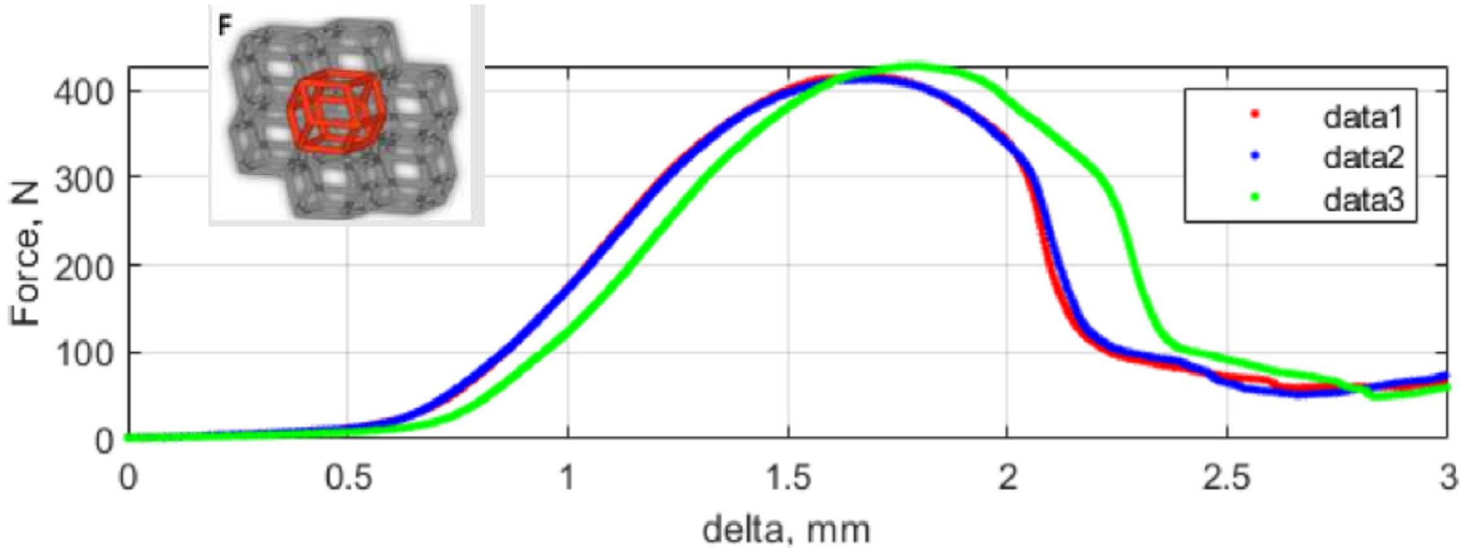


Fig. 9F – Force-displacement experimental relations of F unit (rhombic dodecahedron structure).

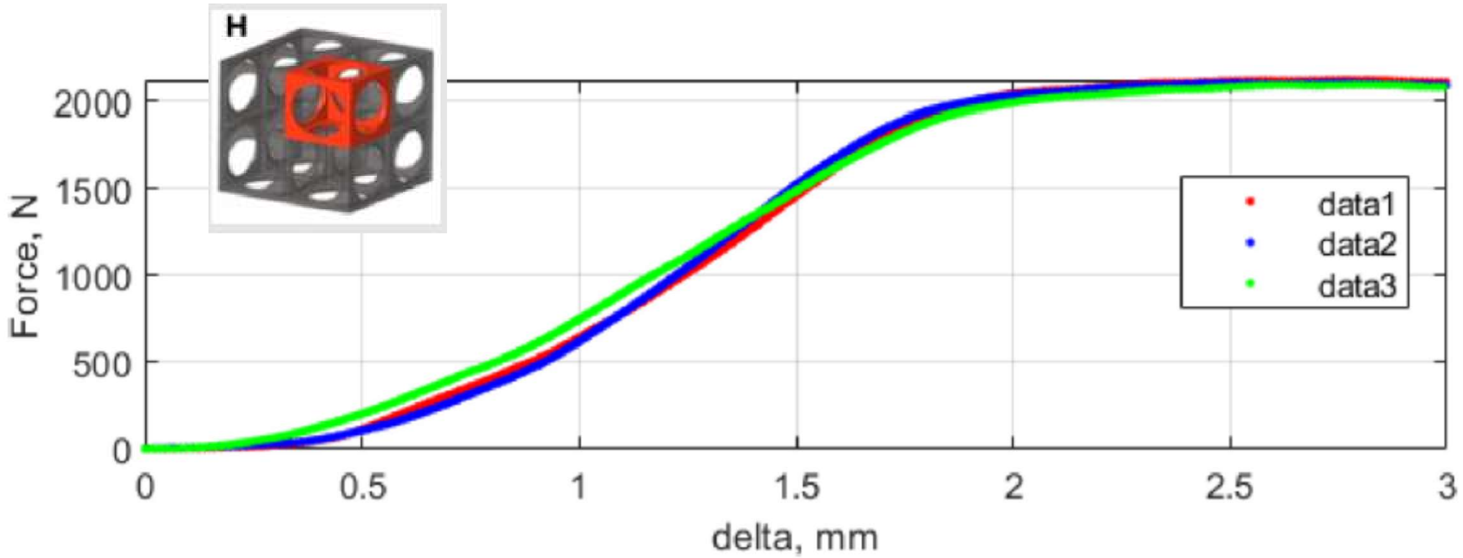
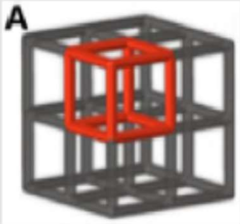
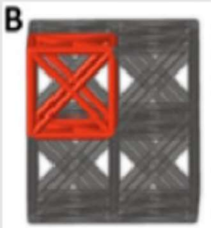
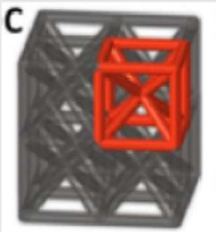
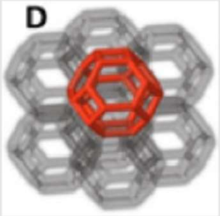
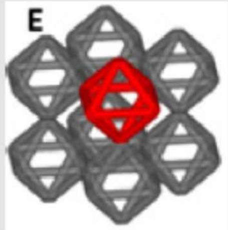
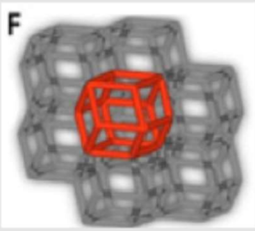
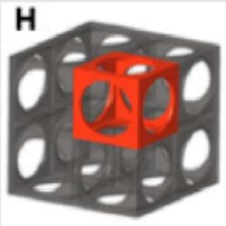


Fig. 9G – Force-displacement experimental relations of H unit (subtractive structure).

Table 3 – Experimental Young modulus results		
Unit	Experimental effective Young modulus [MPa]	Relative error [%]
	A unit (regular cubic structure) E = 117.6 ± 6.4 MPa	30.8%
	B unit (FCC structure) E = 101.8 ± 14.2 MPa	27.3%
	C unit (BCC structure) E = 75.6 ± 6.5 MPa	16.0%

	D unit (truncated octahedron structure) E = 60.8 ± 9.6 MPa	21.6%
	E unit (octahedron structure) E = 59.3 ± 3.3 MPa	18.6%
	F unit (rhombic dodecahedron structure) E = 52.3 ± 0.7 MPa	4.6%
	H unit (subtractive structure) E = 114.2 ± 9.6 MPa	40.0%

Part 4. Clinical study and biomechanical study of patients with muscular dystrophy

Scope: Patients with Muscular Dystrophy (Duchenne Muscular Dystrophy)

Cooperation with:

- Department of Rehabilitation Medicine, Faculty of Health Sciences with Institute of Maritime and Tropical Medicine, Medical University of Gdansk, Gdansk, Poland
- Rare Diseases Centre (Centrum Chorób Rzadkich), Medical University of Gdansk, Gdansk, Poland

Project "The 'e-Pionier - using tertiary education institutions' potential to boost ICT solutions in the public sector', No. WG-POPC.03.03.00-00-0008/16-00, subject of the contract: "***Custom-made device to assist the motor functions of the upper limb with muscular dystrophy***", **2018 – 2020**

Politechnika Gdańska (W.Wojnicz, M.Chodnicki, M.Mazur, M.Kaczmarczyk, K.Forysiak, A.Jednachowska)

Gdański Uniwersytet Medyczny (J.Jabłońska-Brudło, A.Sobierajska-Rek)

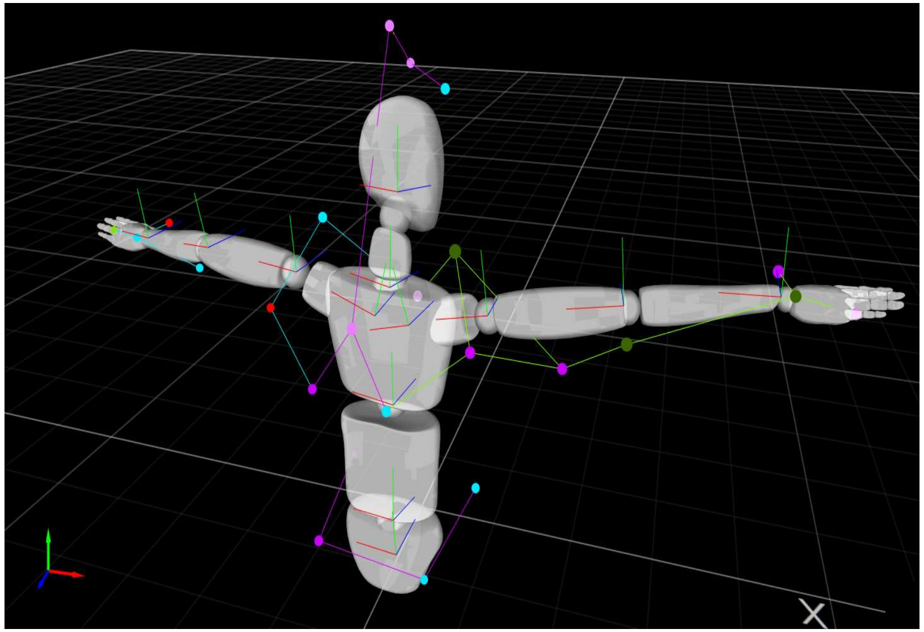
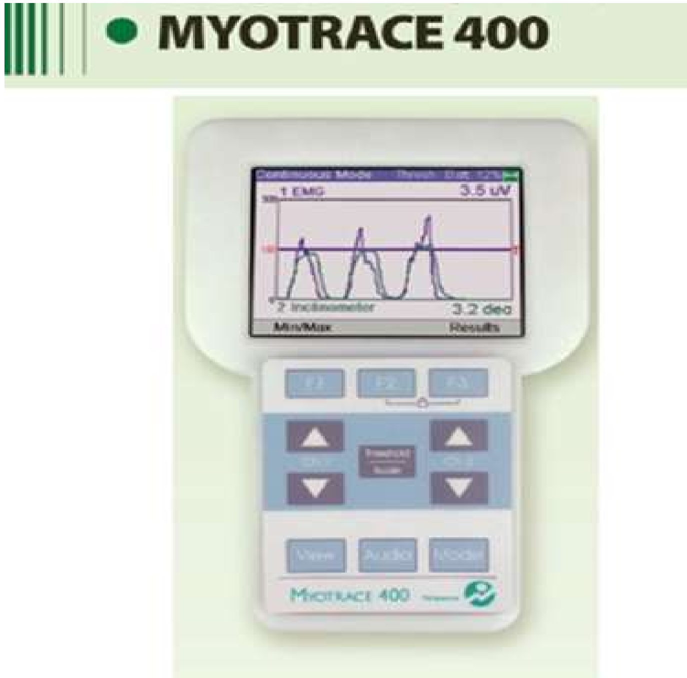
Politechnika Łódzka (B.Zagrodny, M.Ludwicki)

Akademia Górniczo-Hutnicza (R.Barański)

Firma „Koncept Impuls" Bartłomiej Tański

The aim of the project was *to design and build a prototype of active custom-made exoskeleton that helps perform motion of the right upper limb of the chosen DMD patient.*

Biomechanical testing in clinical conditions

OptiTrack System (6 cameras, 120 Hz) Lodz University of Technology	Noraxon MyoTrace 400 (1000Hz) Myoresearch XP software (4 channels) Gdansk University of Technology
	

Prototype of active custom-made exoskeleton that helps perform motion of the right upper limb of the chosen patient with DMD (7DOF)

Application for a patent (for a new invention) "Exoskeleton to help perform motion of upper limb for Duchenne muscular dystrophy patient" (submission 21.10.21). Authors from Gdansk University of Technology and Medical University of Gdansk

https://ewyszukiwarka.pue.uprp.gov.pl/search/pwp-details/P.439272?lng=pl

Article

A New Approach to Assess Quality of Motion in Functional Task of Upper Limb in Duchenne Muscular Dystrophy

Wiktoria Wojnicz [1], Agnieszka Sobierajska-Rek [2], Bartłomiej Zagrodny [3], Michał Ludwicki [3,*], Joanna Jabłońska-Brudło [2] and Katarzyna Forysiak [1]

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[2] Department of Rehabilitation Medicine, Faculty of Health Sciences with Institute of Maritime and Tropical Medicine, Medical University of Gdansk, 80-210 Gdansk, Poland
[3] Department of Automation, Biomechanics and Mechatronics, Faculty of Mechanical Engineering, Łódź University of Technology, 90-537 Łódź, Poland
* Correspondence: michal.ludwicki@p.lodz.pl

Wojnicz W., Sobierajska-Rek A., Zagrodny B., Ludwicki M., Jabłońska-Brudło J., Forysiak K., ***A New Approach to Assess Quality of Motion in Functional Task of Upper Limb in Duchenne Muscular Dystrophy***. Appl. Sci. **2022**, 12, 12247.
https://doi.org/10.3390/app122312247

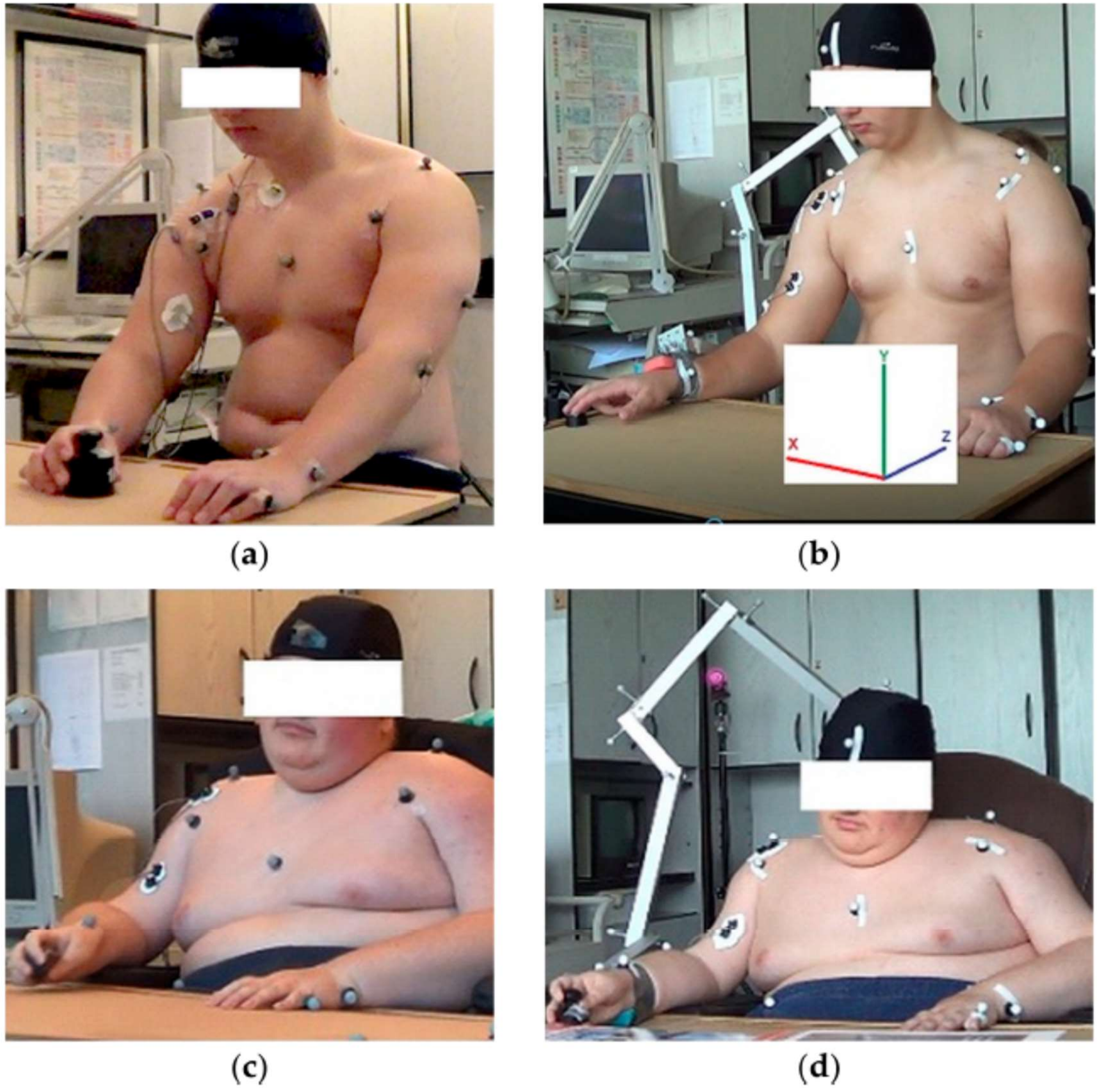


Figure 2. (**a**) Reference subject (RS) under natural conditions (NC); (**b**) Reference subject (RS) with a passive manipulator (under passive manipulator conditions (PMC)); (**c**) DMD patient (DMD) under natural conditions (NC); (**d**) DMD patient (DMD) with a passive manipulator (under passive manipulator conditions (PMC)).

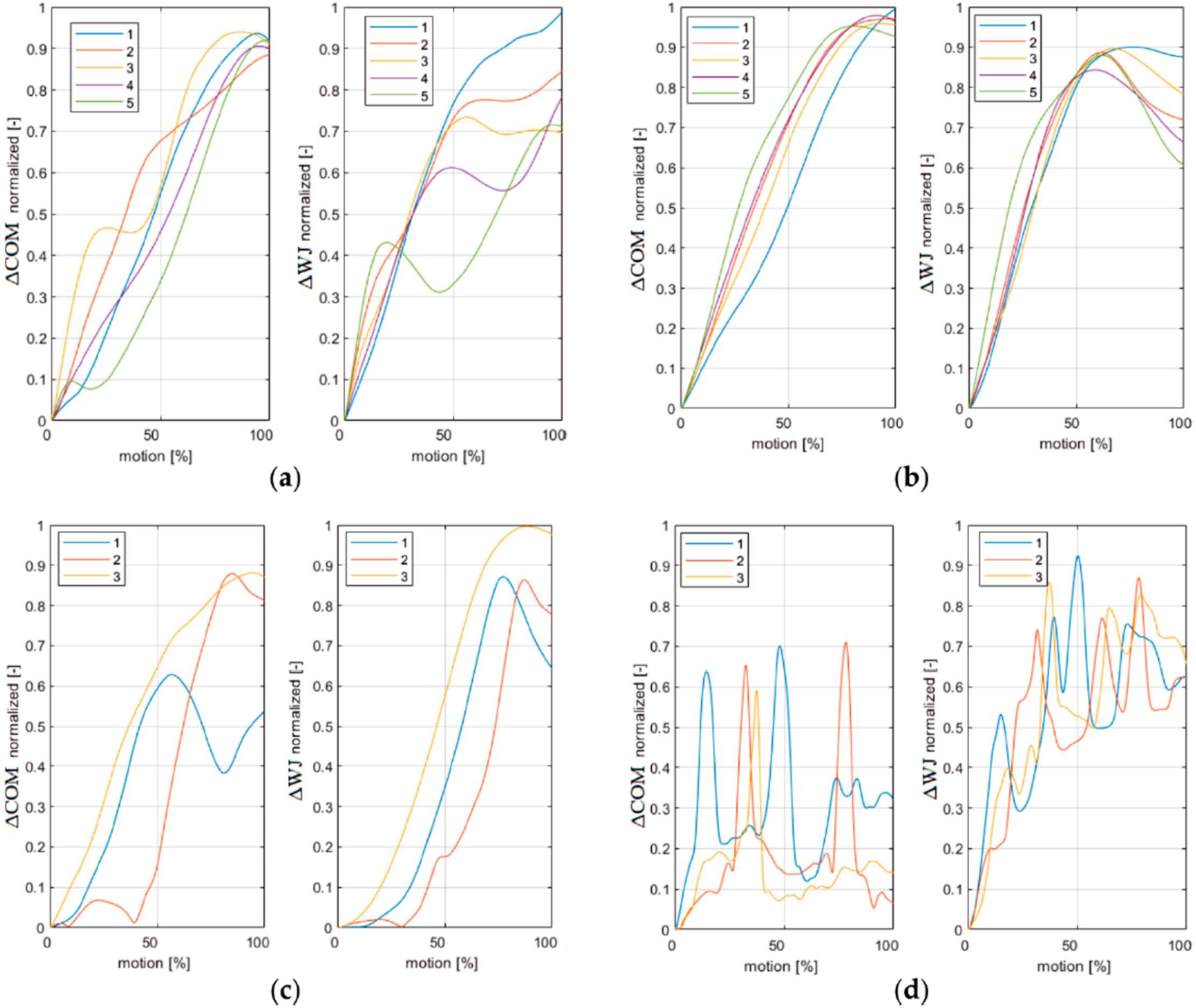


Figure 3. (**a**) Reference subject in **motion1** under natural conditions; (**b**) Reference subject in **motion1** under passive manipulator conditions; (**c**) DMD subject in **motion1** under natural conditions; (**d**) DMD subject in **motion1** under passive manipulator conditions.

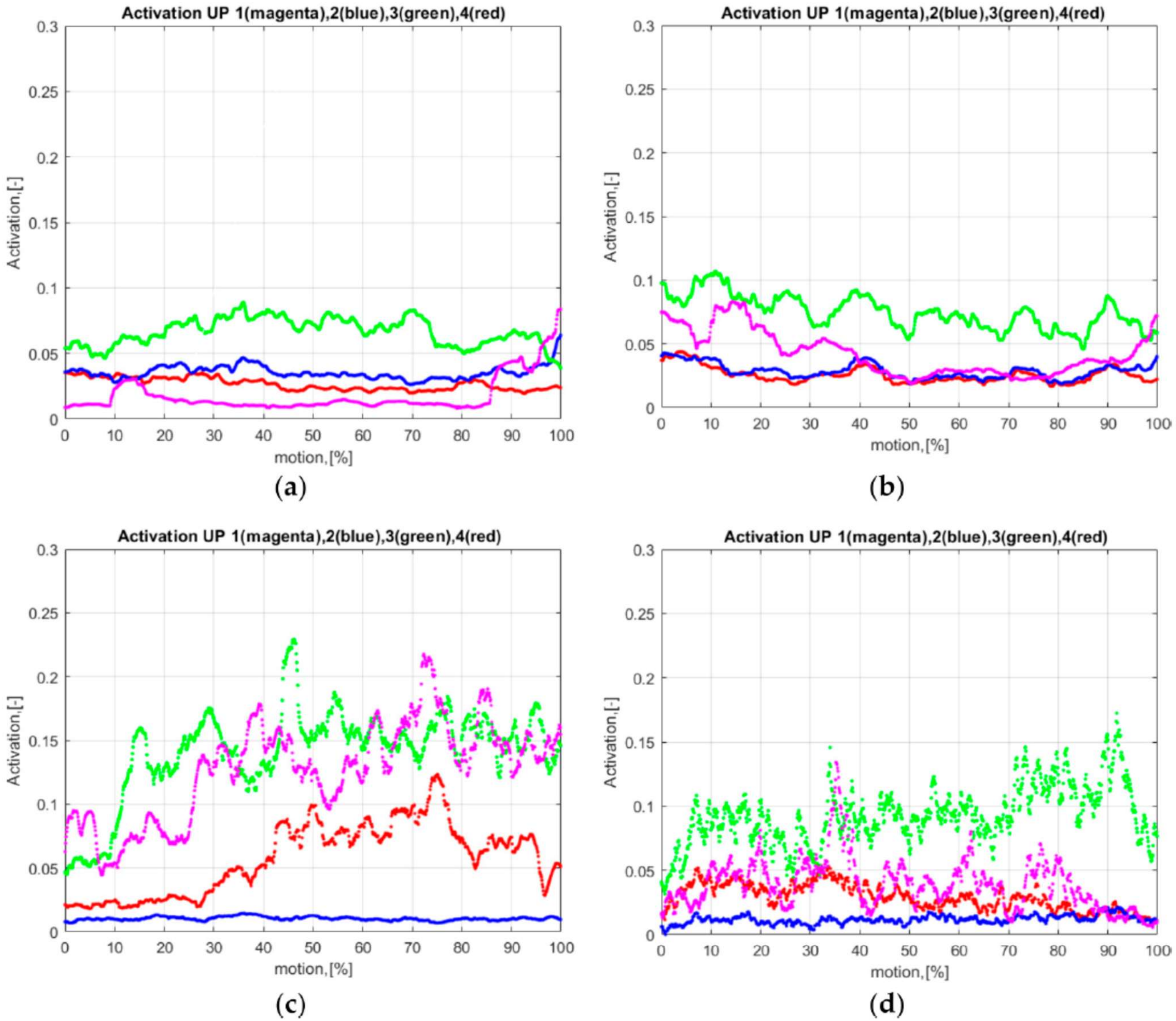


Figure 4. EMG data processed (mean value of the RMS normalized data): BB (EMG_1), TB (EMG_2), AD (EMG_3), and UT (EMG_4): (**a**) Reference subject in **motion1** under natural conditions; (**b**) Reference subject in **motion1** under passive manipulator conditions; (**c**) DMD subject in motion1 under natural conditions; (**d**) DMD subject in **motion1** under passive manipulator conditions.

A motivation of this study was to answer the following questions:

(1) How are the muscles of DMD patients activated in comparison to those of healthy subjects?

(2) What movement strategies do DMD patients use to perform ADL functional tasks?

(3) How does an external passive device influence the kinematics of the movements of DMD patients versus healthy ones in ADL functional tasks?

The purposes of this study:

(1) to propose a new approach to assess the quality of motion in ADL functional tasks under clinical conditions by revealing whether muscle activity is correlated more to the displacement of the upper limb COM or to the displacement of the upper-limb WJ;

(2) to investigate whether different levels of external mass influence the performance of the dominant right upper limbs of DMD patients in natural conditions and using a passive lightweight manipulator that is a low-friction (non-resistant) device.

In this study, the upper limb performance was examined by recording horizontal movements at the level of the waist and the muscle activity of four chosen superficial muscles and then comparing these results to those of a reference subject (a healthy adolescent).

The results of the assessment of the quality of motion are presented in two main parts:

The first part involves the results of the application of a piecewise linear multi-regression to define the contribution of the tested muscles to controlling the displacement of the upper limb COM and the displacement of the upper-limb WJ.

The second part involves the results of the chosen tests of significance aimed at identifying whether the use of a passive manipulator evoked changes in the muscle activity and changes in the kinematics of functional movements.

Conditions

Weight	Control	DMD
Light	+	+
Light with PM	+	+
Heavy	+	+
Heavy with PM	+	+

Muscle activity data

EMG1
EMG2
EMG3
EMG1

Kinematic data

WJx
WJy
WJz
ΔW

COMx
COMy
COMz
ΔCOM

A piecewise linear multi-regression (the first part of approach for assessment of quality of motion) was applied to correlate muscle activations (EMG_1, EMG_2, EMG_3, EMG_4) and the kinematic data of displacement of the wrist joint (WJ_x, WJ_y, WJ_z, ΔWJ) or upper limb COM (COM_x, COM_y, COM_z, ΔCOM) in each tested window that was equal to 1% of the length of the motion fragment (composed of 10 frames). Assuming that muscle activations are independent variables (EMG_1, EMG_2, EMG_3, EMG_4) and each kinematic datum y (WJ_x, WJ_y, WJ_z, ΔWJ, COM_x, COM_y, COM_z and ΔCOM) is dependent variable, the relation was formulated as:

$$y = a_0 + a_1 \cdot EMG_1 + a_2 \cdot EMG_2 + a_3 \cdot EMG_3 + a_4 \cdot EMG_4 = \\ = y_0 + y_1 + y_2 + y_3 + y_4, \quad (1)$$

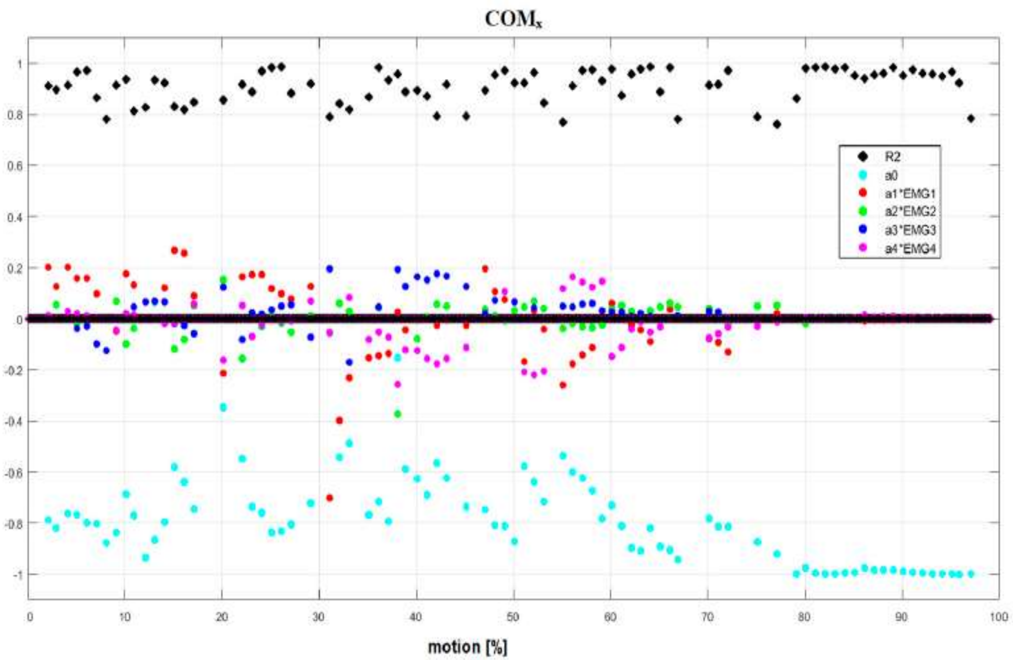
where y_j (for $j = 0, 1, 2, 3, 4$) describes the j-th participation (contribution) in the value of the tested kinematic data y; a_0 describes the contribution of the motion of trunk and fingers, as well as pronation/supination of the wrist joint and/or upper limb passive structures and/or non-monitored active muscles ($a_0 = y_0$); a_i ($i = 1, \ldots, 4$) describes the coefficient of the i-th muscle activation EMG_i (this coefficient depends on the muscle lever arm). The product between this coefficient a_i and muscle activation EMG_i defines the contribution of the i-th muscle to the motion performance, i.e., $a_1 \cdot EMG_1 = y_1$, $a_2 \cdot EMG_2 = y_2$, $a_3 \cdot EMG_3 = y_3$, $a_4 \cdot EMG_4 = y_4$.

Linear piecewise multi-regression analysis was performed in MATLAB by using our own codes and statistics toolbox. Assuming a threshold of statistical significance in which p was equal to 0.05 ($p \leq 0.05$), only statistically significant results of relationships in multi-regression analysis (Equation (1)) with a coefficient of determination (R^2) that was greater than 0.75 ($R^2 \geq 0.75$) were considered.

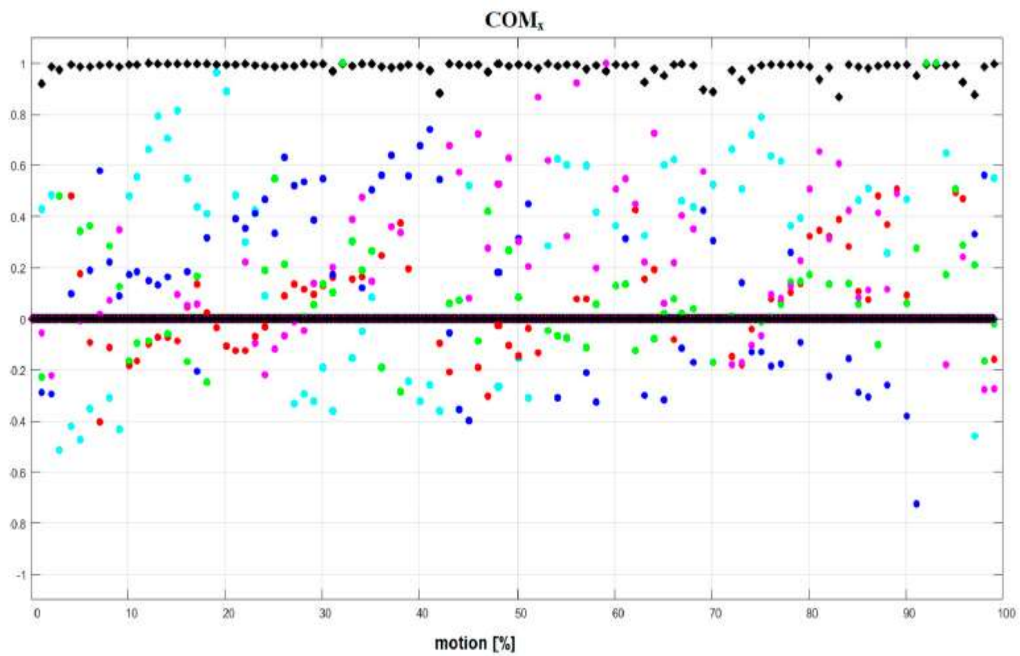
Due to the fact that each muscle contribution (y_1, y_2, y_3, y_4) (Equation (1)) can be positive (synergistic participation), negative (antagonistic), or zero, the results of multi-regression analysis were presented as: (1) distributions of synergistic and antagonistic participation at the time of the motion; (2) summarizing synergistic and antagonistic participations. To consider all of the synergetic and antagonistic participations in each tested window, the i-th muscle contribution y_j was normalized and presented in the form of participation:

$$part_{y_i} = \frac{y_i}{\sum |y_i|}. \quad (2)$$

Figure 5. (**a**) Results of linear piecewise multi-regression analysis performed in each tested fragment of the motion for reference subject in **Motion1** under natural conditions. COM_x. (**b**) Results of linear piecewise multi-regression analysis performed in each tested fragment of the motion for DMD patient in **motion1** under natural conditions. COMx.



(**a**)



(**b**)

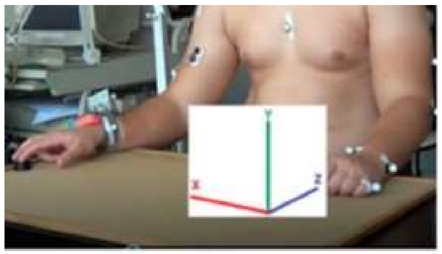


Table S5 – S12 and Figure S67 - S74. Results of linear piecewise multi-regression analysis presenting accumulated synergistic and antagonistic participations calculated between kinematic data and muscular activity for the reference subject and DMD patient in natural conditions and passive manipulator conditions in both motions ($p \leq 0.05$, $R2 \geq 0.75$): the $\boldsymbol{a_1} \cdot \boldsymbol{EMG_1}$ part describes RT TRAPEZIUS muscle participation, the $\boldsymbol{a_2} \cdot \boldsymbol{EMG_2}$ part describes RT LAT. TRICEPS muscle participation, the $\boldsymbol{a_3} \cdot \boldsymbol{EMG_3}$ part describes RT ANT.DELTOID muscle participation, the $\boldsymbol{a_4} \cdot \boldsymbol{EMG_4}$ part describes RT BICEPS BR muscle participation.

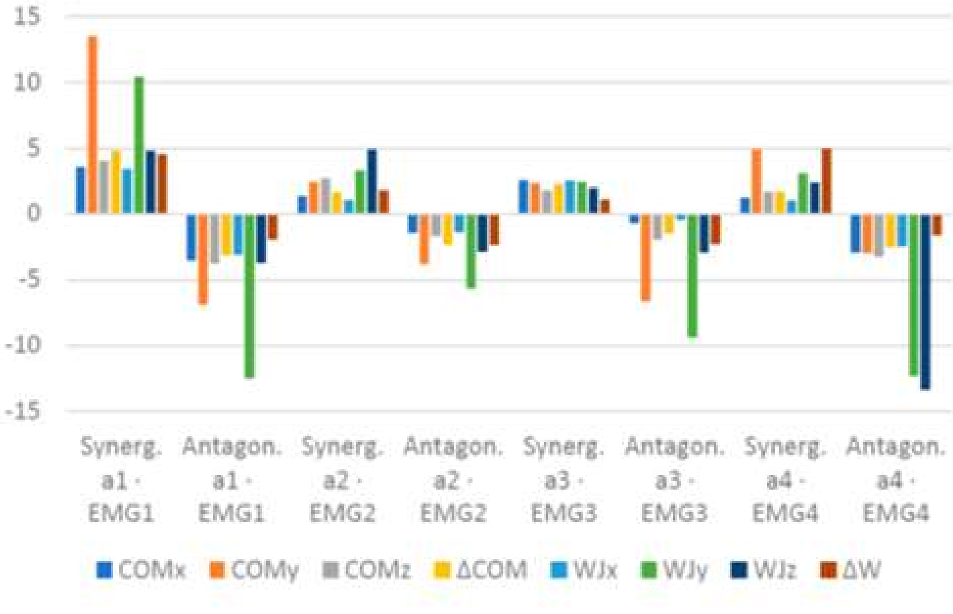


Figure S67 Reference subject. Motion 1. Natural conditions.

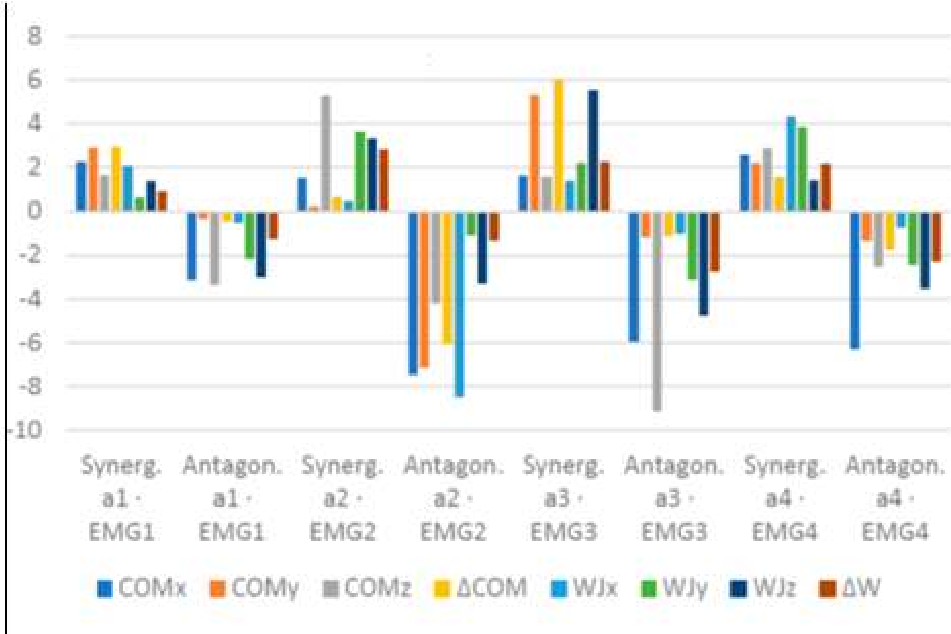


Figure S68. Reference subject. Motion 1. Passive manipulator conditions.

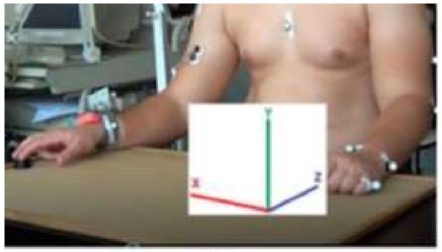


Table S5 – S12 and Figure S67 - S74. Results of linear piecewise multi-regression analysis presenting accumulated synergistic and antagonistic participations calculated between kinematic data and muscular activity for the reference subject and DMD patient in natural conditions and passive manipulator conditions in both motions ($p \leq 0.05$, $R2 \geq 0.75$): the $\boldsymbol{a_1 \cdot EMG_1}$ part describes RT TRAPEZIUS muscle participation, the $\boldsymbol{a_2 \cdot EMG_2}$ part describes RT LAT. TRICEPS muscle participation, the $\boldsymbol{a_3 \cdot EMG_3}$ part describes RT ANT.DELTOID muscle participation, the $\boldsymbol{a_4 \cdot EMG_4}$ part describes RT BICEPS BR muscle participation.

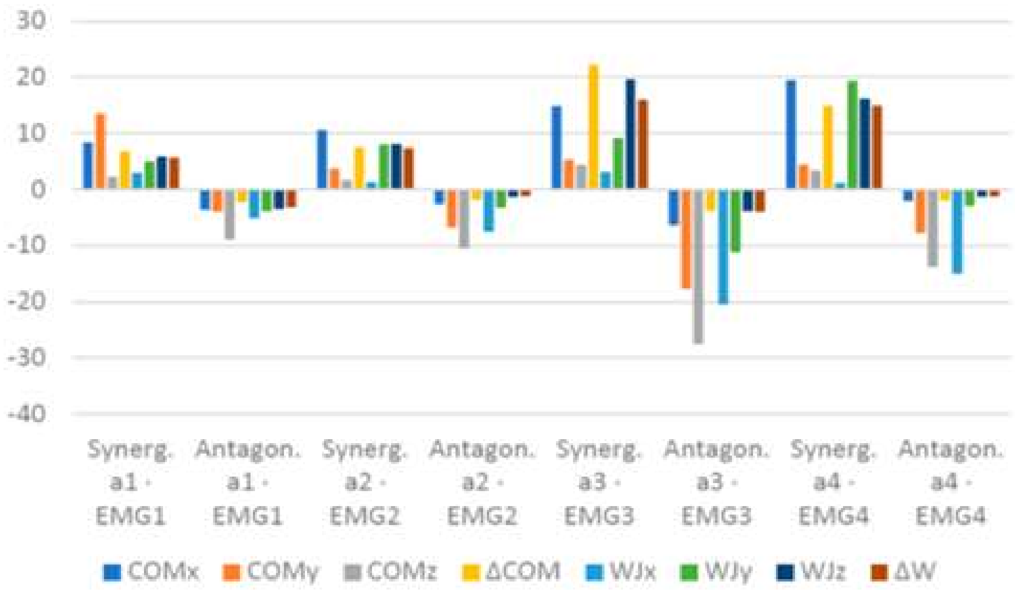


Figure S71. DMD patient. Motion 1. Natural conditions.

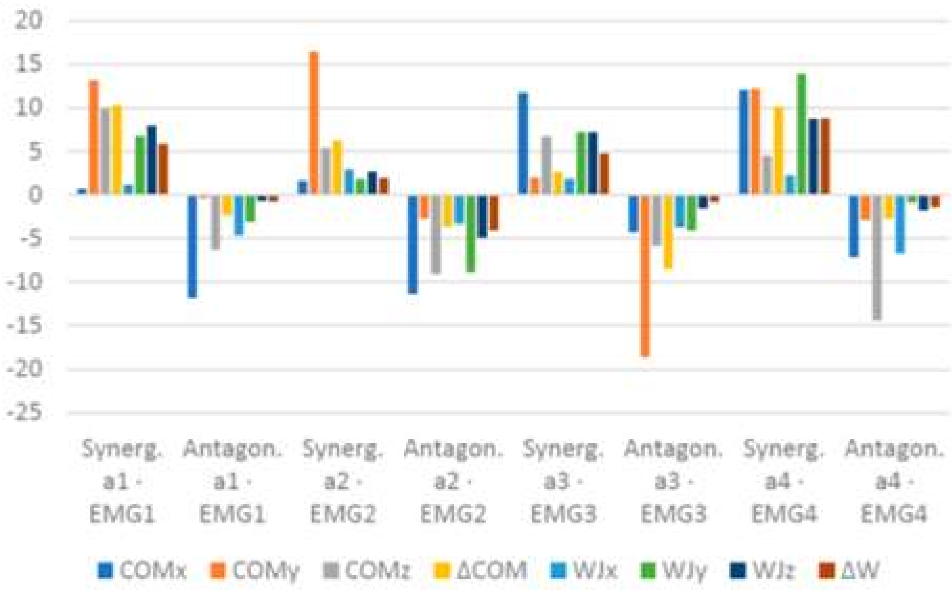


Figure S72. DMD patient. Motion 1. Passive manipulator conditions.

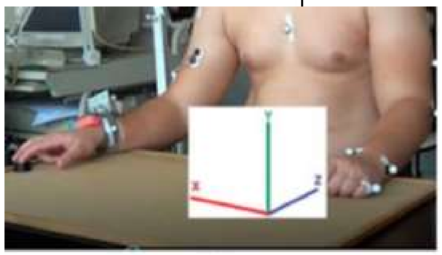


Table S5 – S12 and Figure S67 - S74. Results of linear piecewise multi-regression analysis presenting accumulated synergistic and antagonistic participations calculated between kinematic data and muscular activity for the reference subject and DMD patient in natural conditions and passive manipulator conditions in both motions ($p \leq 0.05$, $R2 \geq 0.75$): the $\boldsymbol{a_1 \cdot EMG_1}$ part describes RT TRAPEZIUS muscle participation, the $\boldsymbol{a_2 \cdot EMG_2}$ part describes RT LAT. TRICEPS muscle participation, the $\boldsymbol{a_3 \cdot EMG_3}$ part describes RT ANT.DELTOID muscle participation, the $\boldsymbol{a_4 \cdot EMG_4}$ part describes RT BICEPS BR muscle participation.

Figure S69. Reference subject. Motion 2. Natural conditions.

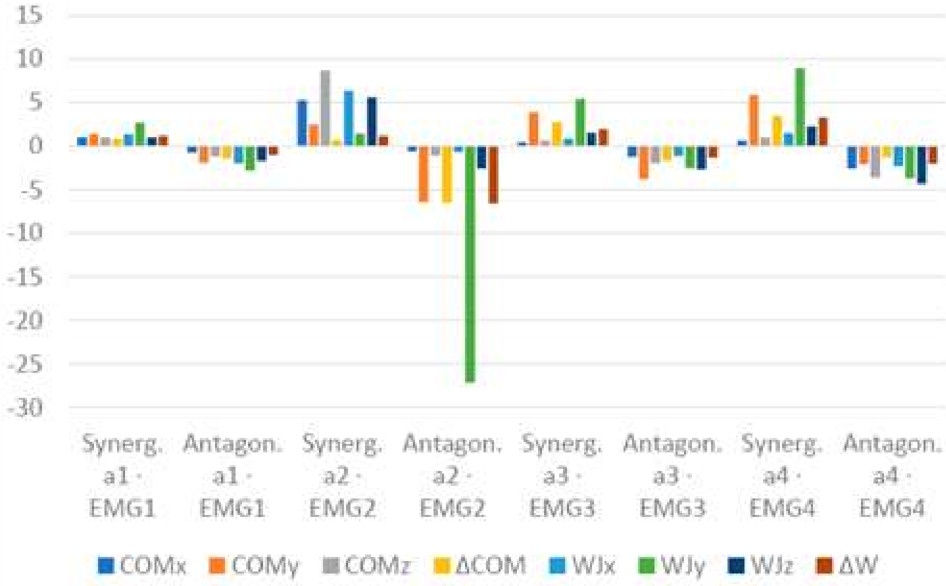


Figure S70. Reference subject. Motion 2. Passive manipulator conditions.

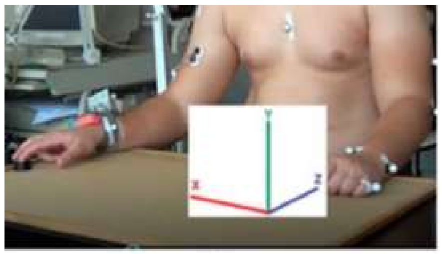


Table S5 – S12 and Figure S67 - S74. Results of linear piecewise multi-regression analysis presenting accumulated synergistic and antagonistic participations calculated between kinematic data and muscular activity for the reference subject and DMD patient in natural conditions and passive manipulator conditions in both motions ($p \leq 0.05$, $R2 \geq 0.75$): the $\boldsymbol{a_1 \cdot EMG_1}$ part describes RT TRAPEZIUS muscle participation, the $\boldsymbol{a_2 \cdot EMG_2}$ part describes RT LAT. TRICEPS muscle participation, the $\boldsymbol{a_3 \cdot EMG_3}$ part describes RT ANT.DELTOID muscle participation, the $\boldsymbol{a_4 \cdot EMG_4}$ part describes RT BICEPS BR muscle participation.

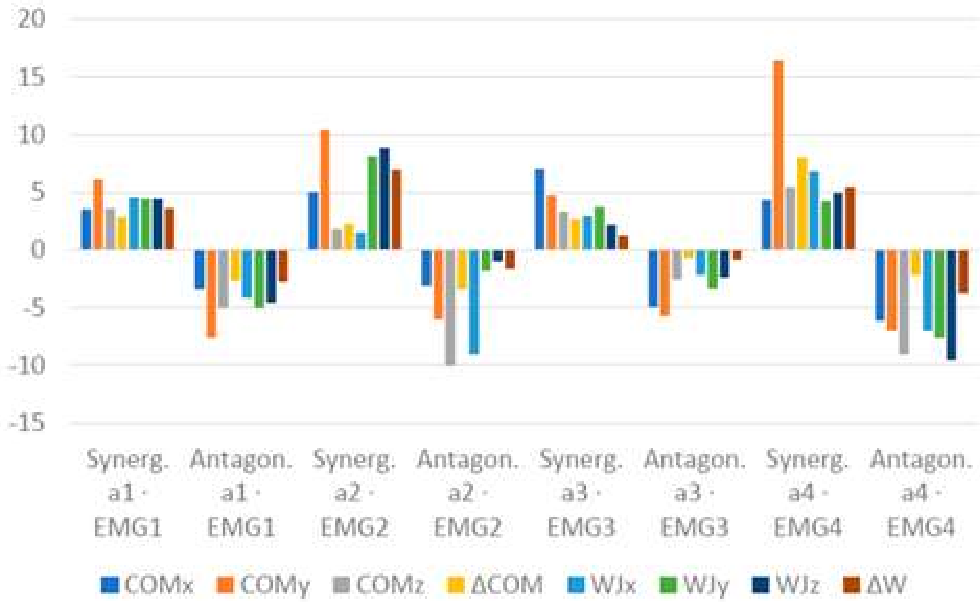
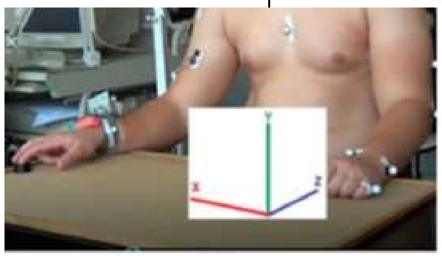


Figure S73. DMD patient. Motion 2. Natural conditions.

Figure S74. DMD patient. Motion 2. Passive manipulator conditions.



5.2. Recommendation

Using a passive manipulator, DMD patients can learn to use an active exoskeleton in a guidance mode. Our study can be used to address the main question in the field of DMD physiotherapy: whether the application of a passive manipulator can evoke a neural command which can better control muscles and move the arm of a DMD patient in a smoother way [32,33].

THANK YOU FOR YOUR ATTENTION!