Digital Manufacturing 4.0
Human-centered Workplaces of the Future with Integrated Exoskeletons: Digital Twin Exo4LogiProd

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Cognitive Engineering and Production, “Digital Manufacturing 4.0”
Overview

- About Us: Fraunhofer Society, Fraunhofer Institute for Industrial Engineering
- My Experience in dealing with »Digital Manufacturing«
- Challenges for ergonomic workplaces in manufacturing and Musculoskeletal Disorder – MSD
- Exoskeleton technology – Modular concept. Benefits, Challenges
- Digitalisation of human-centred workplaces with integrated Exoskeletons. Application examples
- Exo4LogiProd – 4 Steps methodology
- Demonstration in FutureWorkLab: active and passive Exoskeletons
German Science and Education after 1945

1829 "Vereinigte Real- und Gewerbeschule" in Stuttgart - Wilhelm I. von Württemberg

1946 College of Technology, 1967 ⇒ Universität Stuttgart

1948 Kaiser-Wilhelm-Gesellschaft ⇒ Max-Planck Society (MPG)

1949 Fraunhofer Society for Applied Science (FhG)

1951 German Research Foundation (DFG)

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Joseph von Fraunhofer (1787 - 1826)

**Researcher:**
Discovery of »Fraunhofer Lines« in the sun spectrum 1814.

**Inventor:**
New methods of lens processing.

**Entrepreneur:**
Head of Royal Glass Factory.

- 72 institutes and independent research units
- 26,600 employees
- Annual research budget: 2.1 billion euros*
- >1.8 billion euros from contracted research*

*Figures for 2018
Fraunhofer Institute for Industrial Engineering IAO
Institute of Human Factors and Technology Management, University of Stuttgart

- **Founded:** IAO – 1981, IAT – 1991
- **Budget:** 51.8 million euros, of which 33.7% are generated from industry
- **Staff:** ~650 employees

Figures from 2018, including IAT University of Stuttgart

- **Areas of Expertise:**
  - Corporate Development and Work Design
  - Service and Human Resources Management
  - **Cognitive Engineering and Production**
  - Information and Communication Technology
  - Technology and Innovation Management
Which are the most challenging workplaces?

**Components assembly / disassembly**
- Car headlights assembly (BCM)
- Battery disassembly (BDRA)

**Working over the head**
- Protective shield assembly screwing (BMW)
- Welding in the container (Einsenbau)

**Logistics**
- Manipulation of heavy parts (Einsenbau)
- Relocation processes

**Maintenance**
- pallet assembly / disassembly (Siemens)
- Rotor disassembly

**Hardly fully automation**
- Small lot sizes
- Complex tasks
- Required Human precision and flexibility
- High variability

**Manipulation of heavy parts** (Lifting, Lowering, Carrying, Twisting) and Working over the head
What is Musculoskeletal Disorder - MSD?

Critical MSD facts:
- Chronic back pain (MSD): 80-90
- Depression: 20-30
- Rheumatoid arthritis: 50-60
- Asthma: 55-75
- High blood pressure: 70-80

Medical prevention costs
Loss of productivity

Source: Bertelsmann/Booz & Company 2017
Exoskeleton technology? Modular Concept

- Complexity
  - Mass, volume, system complexity (sensors, actuators, control loops), power requirement, safety measures, time to develop, costs

- Body weight compensation
  - Augmented force
  - Production tool

- Robo-Mate
  - Physical Assistant Robots for Co-Production – adherence to ISO 13482
Passive Exoskeletons and applications in manufacturing

- **Working over the head**
  - AIRFRAME © (Levitate Technologies Inc.)

- **Tool holder**
  - Fortis © (Lockheed Martin)

- **Static processes**
  - Chairless Chair © (Noonee)
  - Laevo © (Laevo B.V.)
Active Exoskeletons: Research prototype and commercial product

ExoJacket: Fraunhofer IPA – Research active Exoskeleton demonstrator for upper body support and protection

CrayX: German Bionic Systems GmbH – Active commercial Exoskeleton for lower back support and protection
Motivation for Exoskeleton-based Workplaces

**Exoskeletons:**
- technology for **ergonomics**, **safety** and **environmentally friendly** workplaces (lowering, lifting, carrying and twisting of heavy goods and working over the head);
- increases and stimulates innovation, concentration capability, self-esteem

**Benefits:**
- Ergonomic and safety workplaces
- Increased worker safety, security, satisfaction, motivation
- Enhanced worker capabilities: concentration, innovation
- Increased industrial sustainability:
  - social (ergonomics, safety);
  - environment (CO2);
  - productivity (high quality, precision, innovation).

**Technical challenges:**
- Comfort: up to 8 hour shifts, new work models?
- Unhindered movements
- Initial settings, wear/un-wear time; external support
- Power supply
- Mental harassment
- Captured data security, confidentiality, anonymization
- ELSI aspects: ethic, legal, social
Design and optimization of human-centered workplaces with integrated Exoskeletons – Exo4LogiProd

1. **Digital Twin** of „As it is“ State

2. Ergonomics simulation of „As it is“ State

3. **Human+Exo Digital Twin** - Coupling Exoskeleton and Human Digital Twins

4. Ergonomics simulation of the „As it should be“ State with **Human+Exo Digital Twin**

5. Analysis „As it is“ vs. „As it should be“ States

6. Planning/optimisation of hybrid workplace with integrated Exoskeletons. Hybrid working models. Implementation Roadmap and incremental improvements
Digital Transformation with Exoskeleton? (I)

**Car recycling Test Case:** Removal of the driver’s seat and of the battery

- Manipulated part: 25kg and 15kg;
- Distance walked per day: 1200m;
- Weight moved per day: 700kg.

**Without Exoskeleton**

**With Active Exoskeleton**

**Lower Back Analysis Tool:**
1) Forces (N); 2) Moments (Nm); 3) Muscle Tension (N); 4) DMH – Moment distribution
Digital Transformation with Exoskeleton? (II)

**Car assembly Test Case:** Working over the head - Shields Mounting

- Manipulated part: Screwing Machine 1.6kg;
- Distance walked per day: 700m;
- Process time/screw: 0.73 seconds;
- No. of screws: 13
- Torque Moment applied on the workers hand: 2.6Nm.

**Without Exoskeleton**

**With Passive Exoskeleton**

**Force Solver Analysis Tool:** Health of body joint based on frequency, cycle time, shift duration
Construction industry: Manipulation of heavy parts

Test Case: Removing cement blocks for the Silos Maintenance

- Weight of the manipulated part: 20kg;
- Number of the manipulated parts/day: 250;
- Hours/Shift: 10;
- Weight moved by workers per day: 5000 kg.
Digital Transformation with Exoskeleton? (IV)

Logistics industry: Manipulation of heavy goods/parts

Test Case: Placement of a box on the conveyor belt.

- Weight of manipulated part: > 25 kg;
- Number of manipulated parts/shift: 125;
- Distance walked by workers per day: ~5.500 m;
- Weight moved by workers per day: ~ 3.500 kg.
Reference projects

Research:

**BMBF: ExoLogiProd** - Arbeitsplätze der Zukunft mit integrierten intelligenten Exoskeletten für Logistik- und Produktionsprozesse in KMU (2019-2022)

**BMBF: Handwerk4.0** – Exoskeleton and Human-Robot Collaboration (in preparation)


Industry:

- Automotive
- Construction
- Energy
- Logistics
- Food Processing
Real-time motion capture technology

- Wearable sensor platform: 17 motion capturing sensors displaced all over the body for every movement part/joint
- MVN (Motion Virtualisation Technology)
- Analyze output supports joint angles, segment kinematics, segment global positions, and extensive sensor data.
Manipulation of heavy loads – Active Exoskeleton

- Weight of the manipulated part: 15kg;
- Motion capture device reproduces in the virtual environment the movement and behavior of the human worker;
- The human worker is enhanced with a lower back support – Exoskeleton – manufactured by GBS
  (https://www.germanbionic.com/)
Working over the head – Passive Exoskeleton

Working over the head in controlled environment

- Working over the head – assembly tasks
- Motion capture device reproduces in the virtual environment the movement and behavior of the human worker;
- The human worker is enhanced with a upper-limbs support – Exoskeleton – manufactured by SkelEX© (https://www.skelex.com/)

Xsens – Motion capture worker with SkelEX © Exoskeleton
Many warmly thanks!

Digital Twin Exo@Manufacturing2.0