Contactless Gripping – Paving the Way Towards Flexible Micromanipulation

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Introduction of the Power Electronic Systems Laboratory (PES)

21 Nobel Prizes
413 Professors
6240 T&R Staff
2 Campuses
136 Labs
35% Int. Students
110 Nationalities
36 Languages
150th Anniv. in 2005

Departments of ETH Zurich

ARCH Architecture
BAUG Civil, Environmental and Geomatics Eng.
BIOL Biology
BSSE Biosystems
CHAB Chemistry and Applied Biosciences
ERDW Earth Sciences
GESS Humanities, Social and Political Sciences
HEST Health Sciences, Technology
INFK Computer Science
ITET Information Technology and Electrical Eng.
MATH Mathematics
MATL Materials Science
MAVT Mechanical and Process Engineering
MTEC Management, Technology and Economy
PHYS Physics
USYS Environmental Systems Sciences
Energy Research Cluster @ D-ITET

- Balance of Fundamental and Application Oriented Research
PES Research Scope

Power Electronics

Cross-Departmental
- Mechanical Eng., e.g. Turbomachinery, Robotics
- Microsystems
- Medical Systems
- Economics / Society

Actuators / EL. Machines

- Airborne Wind Turbines
- Micro-Scale Energy Systems
- Wearable Power
- Exoskeletons / Artificial Muscles
- Hybrid Systems
- Pulsed Power
Innovation in Mechatronics and Electric Drives

■ Key Components Available Today

- Ultra-Compact & Efficient Power Converter
- High-Speed Digital Signal Processing
- Precision Sensors
- High-Performance Mechanical Actuators
- Ultra-Compact & Efficient Electrical Machines

■ Extremely Wide Application Areas
Industry Trend: High Rotational Speed for High Power Density

Emerging Applications

- Surgical and dental drills
- PCB drilling and micromachining spindles
- Micro turbines and compressors
- Industrial gas turbines
- Prototype Systems
- μm-Scale PCB Drilling
- Dental Technology
- Laser Measurement Technology
- Turbo-Compressor Systems
- Air-to-Power
- Artificial Muscles
- Mega Gravity Science

Source: Zwyssig et al., Megaspeed Drive Systems: Pushing Beyond 1 Million r/min, IEEE Transactions on Mechatronics 2009
World Record Magnetic Bearing with 500’000 r/min

Source: Baumgartner and Kolar, Multivariable State Feedback Control of a 500 000-r/min Self-Bearing Permanent-Magnet Motor, IEEE Transactions on Mechatronics 2015

Source: nasa.gov
High Complexity of Active Levitation Systems

- **Active Magnetic Levitation**
  - Sensing Difficult for Small Rotors
  - High Bandwidth / Complex Control

- **Passive Magnetic Levitation**
  - High Eddy Current Losses

- **Passive Acoustic Levitation**
  - Particle < Wavelength
  - Acoustic Pressure Field
  - Ultrasound Transducers

+ Passively Stable
+ Low Losses
- Low Load Capacity

Source: https://www.instructables.com/id/Acoustic-Tractor-Beam/
Transducer Arrangements and Modelling

- **Individual Excitation of Transducer Arrays**
  - Manipulation of all Degrees of Freedom Possible
  - Achievable Force/Torque Dependent on Transducer Arrangement

\[ p = \sum_{j=1}^{N} p_j \]

\[ p_j = e^{i\phi} M_j \]

\[ M_j = P_0 J_0(kr \sin \theta) \frac{1}{d} e^{ikd} \]

Transducer Piston Model

Source: Marzo et. al., Holographic acoustic elements for manipulation of levitated objects, Nature Communications 2015
Types of Acoustic Traps

- **Twin Trap**: Provides Sufficient Load Capacity and High Radial Stiffness
  - Spatial Rotation of Trap

**Source**: Marzo et. al., Holographic acoustic elements for manipulation of levitated objects, Nature Communications 2015
**High Speed Rotation in Acoustic Traps**

**Twin Trap**
- Approx. Constant Suspension Forces by Non-Linear Phase Shift
- Stability over Wide Speed Range
Highest Rotational Speed of 216,000 r/min
Robotic Grippers Lag Miniaturization Trend

The Information

“What Apple Learned From Automation: Humans Are Better”

Contact-based gripping increasingly unsuitable for small objects
Acoustic Robotic Gripper

Handling of Components
- Without Mechanical Contact
- Damage and Contamination Free
- Handling of Small Objects and Liquids
- Multiple Object Geometries

Processes Automation
- Automated Insertion of Components Required for Pick & Place Processes
Mechatronic System for Precise Force Generation

Object size | < 8 mm
Mass | < 250 mg
Accuracy | ≤ 100 µm
Range | ± 30 mm

M3 hex nut
Ultrasound transducers (72 x)
Control software

Double-sided pick & place
Picking Process: Double and Single-Sided Gripper

“Automated Insertion of Objects Into an Acoustic Robotic Gripper”
Marc Röthlisberger, Marcel Schuck, Laurenz Kulmer and Johann W. Kolar
Single-Sided Picking from Reflective Surfaces

Maximum attainable pressure for each point in space

\[ M(x, y, z) = \sum_j V_{RMS} P_0 \left( \frac{I_0(kr \sin \theta_{d,j})}{d_{d,j}} + R \frac{I_0(kr \sin \theta_{r,j})}{d_{r,j}} \right) \]
Single-Sided Picking from Reflective Surfaces

(a) (b) (c) (d)
Application Example: Liquid Handling

GRIP OBJECTS WITHOUT TOUCHING THEM
Automate processes that had to be performed manually before.

SAVE TIME AND MONEY
The same gripper can be used for a variety of object shapes.

INCREASE QUALITY AND YIELD
Damage and contamination-free handling of precious components.

IMPROVE ENVIRONMENTAL FOOTPRINT
Reduced production rejects.
Application Example: Cell Manipulation

- Manual cell sorting is slow and unreliable
- Results are difficult to replicate
- Precision too low
- Contamination and damage
  → High cost and low yield
Application Example: Cell Manipulation

- Power Electronics
- Ultrasound Transducer-Array
- Transducer
- Glass Slide
- Cell Suspension

Image: Microscope setup with labeled components.
Plattform Technology With a Wide Range of Applications

<table>
<thead>
<tr>
<th>No-Touch Robotics</th>
<th>Micromechanics &amp; Watchmaking</th>
<th>Semiconductor Industry</th>
<th>Life Sciences</th>
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</thead>
<tbody>
<tr>
<td>Automate manual processes</td>
<td>✓</td>
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<tr>
<td>Contamination and damage free</td>
<td>✓</td>
<td>✓</td>
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<td>Variable shape components</td>
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<td>Fluid handling/dispensing</td>
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<td>Improved quality &amp; yield</td>
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<td>No particle generation</td>
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<tr>
<td>Isolation of hazardous substances</td>
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<td>✓</td>
<td>✓</td>
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Thank You!

(Image courtesy of Daniel Steinert)