Automated Insertion of Objects Into an Acoustic Robotic Gripper

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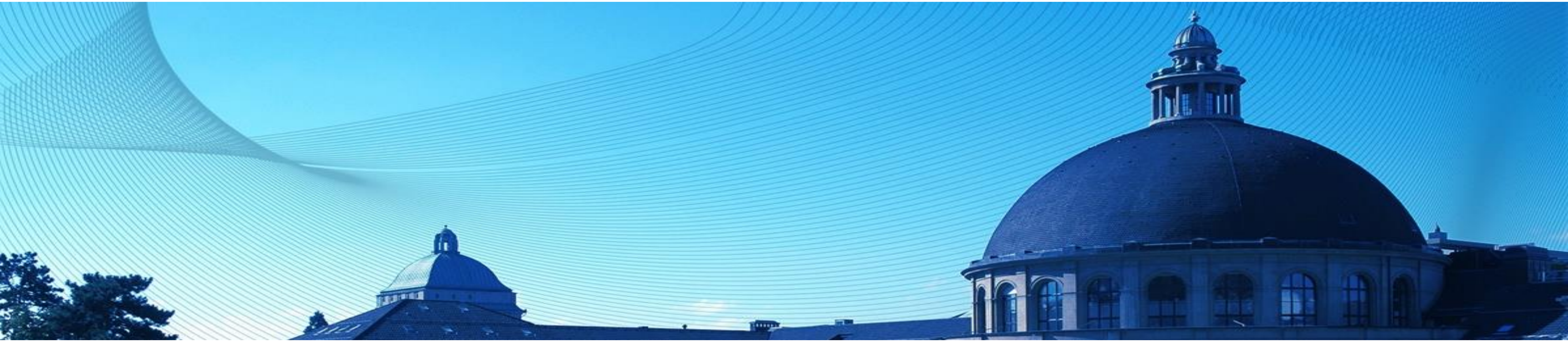
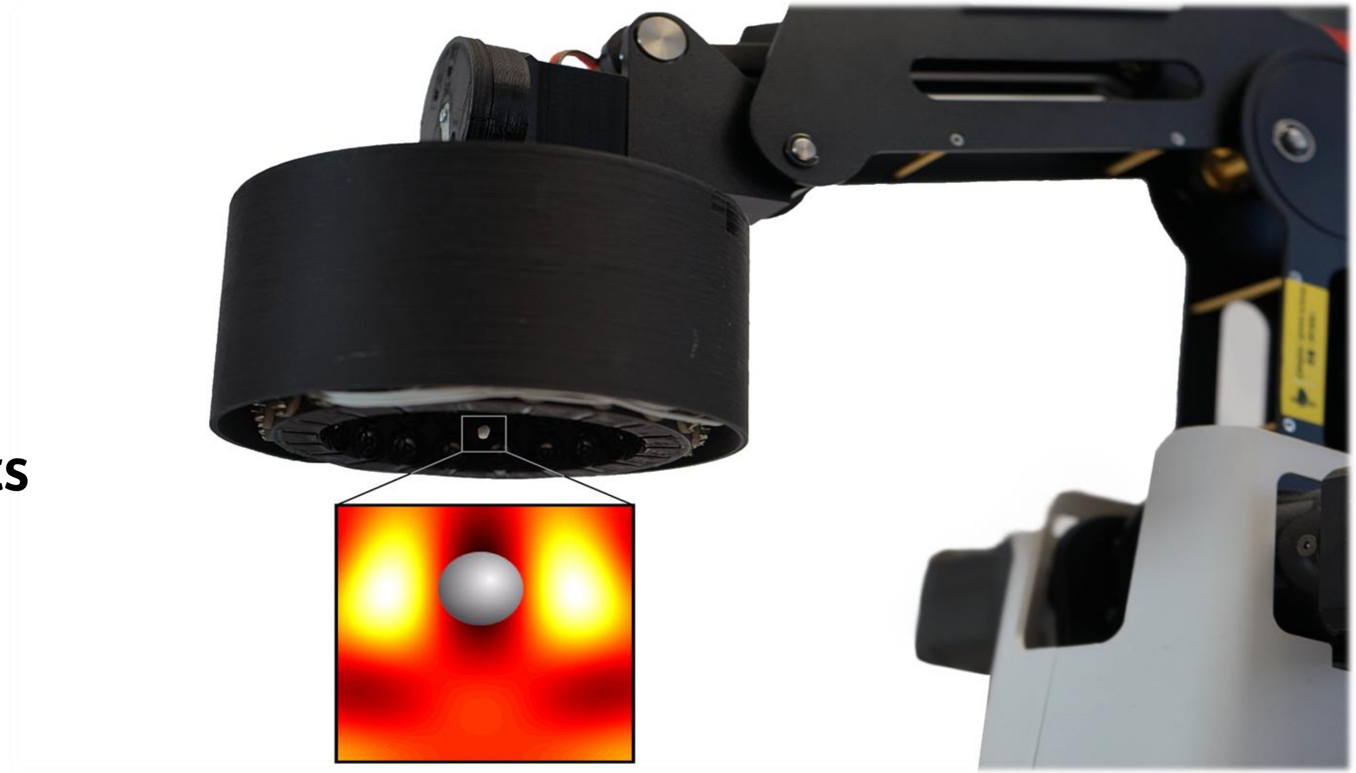


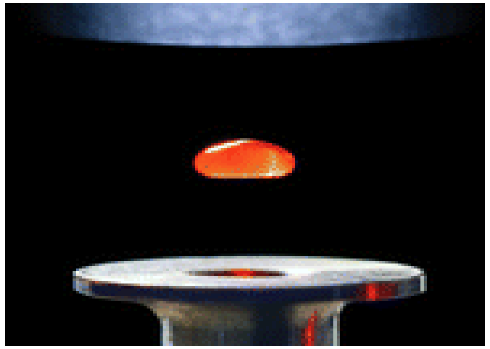
Outline

- Motivation
- Operating Principle
- Picking Process
- Experimental Results
- Conclusion

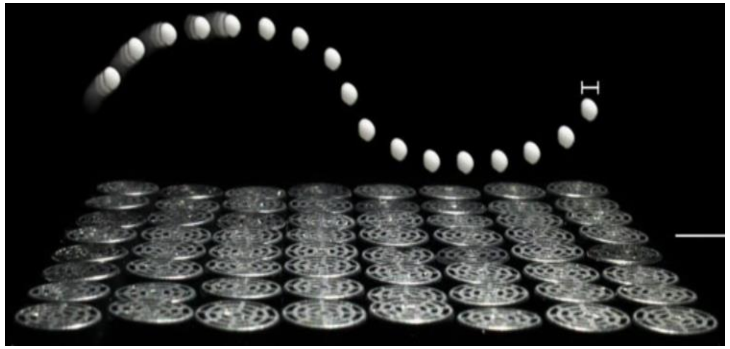


Motivation

Acoustic Levitation



Puskar L. «Raman acoustic levitation spectroscopy of red blood cells and Plasmodium falciparum trophozoites»



Marzo A. «Holographic acoustic elements for manipulation of levitated objects»

- **Standing Wave Levitation**
  - Single Transducer and Reflector
  - No Manipulations
- **Array of Ultrasonic Transducers**
  - Array Instead of Single Transducers
  - Rotation and Translation of Levitating Objects
- **Acoustic Robotic Gripper**
  - Long Range Movements
  - Contactless Automation of Pick & Place Processes

1866 — **2015** — **2020**

Motivation

Acoustic Robotic Grippers

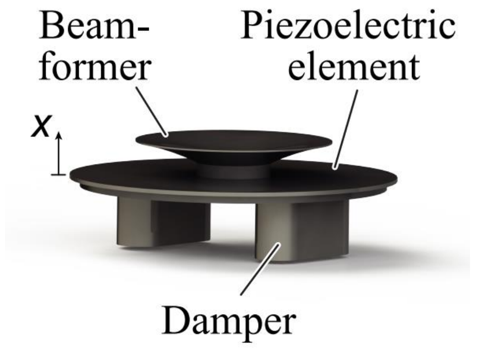
- **Handling of Components**
  - Without Mechanical Contact
  - Damage and Contamination Free
  - Handling of Small Objects and Liquid
  - One Gripper for Multiple Object Geometries
- **Automation of Processes**
  - Automated Insertion of Components Required for the Automation of Pick & Place Processes

Operating Principle

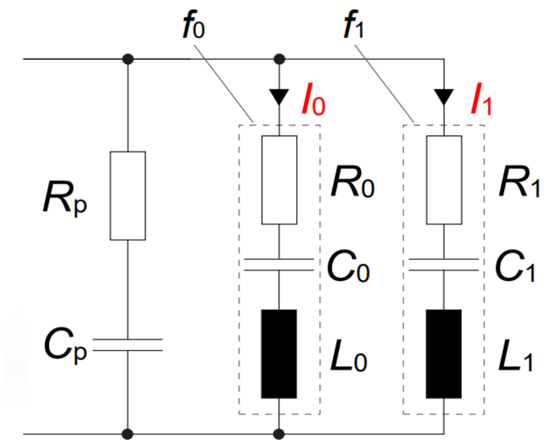
Piezoelectric Transducers

- **Acoustic Pressure**
  - $p = e^{i\varphi} V_{\mathrm{RMS}} P_0 J_0(kr\sin\theta)\frac{1}{d}e^{ikd}$

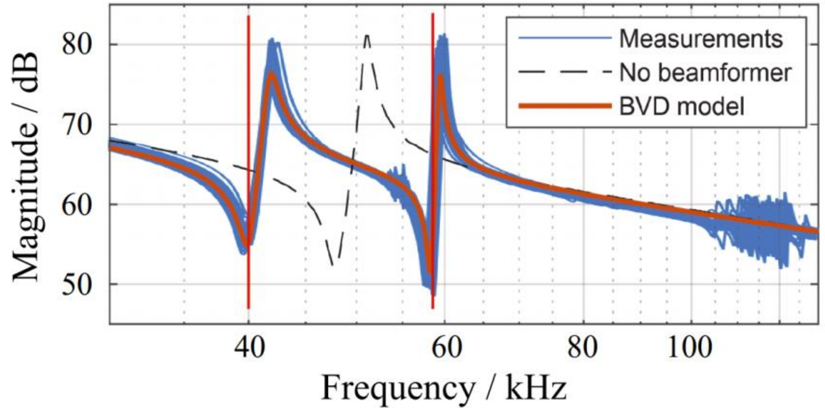
- **P_0: Pressure at $d = 1$ m for $V_{\mathrm{RMS}} = 1$ V**
  - $P_0 \propto \hat{x} \propto \hat{Q} \propto \hat{\imath} = \frac{V_{40}}{Z_{40}}$



Mechanical Structure



Butterworth-Van Dyke Equivalent Circuit



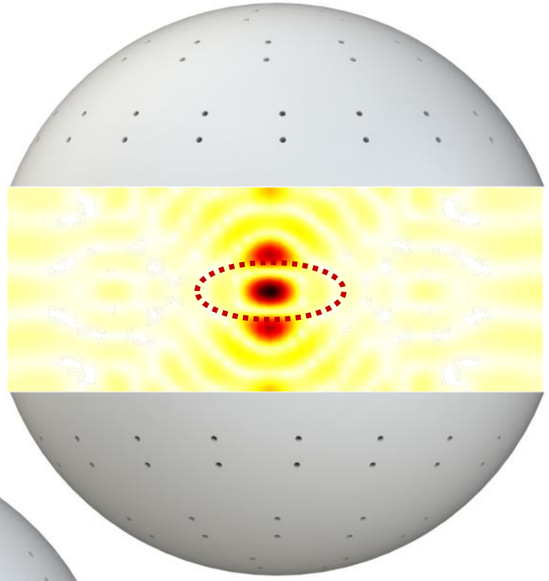
Frequency-Dependent Impedance

Operating Principle

Acoustic Forces

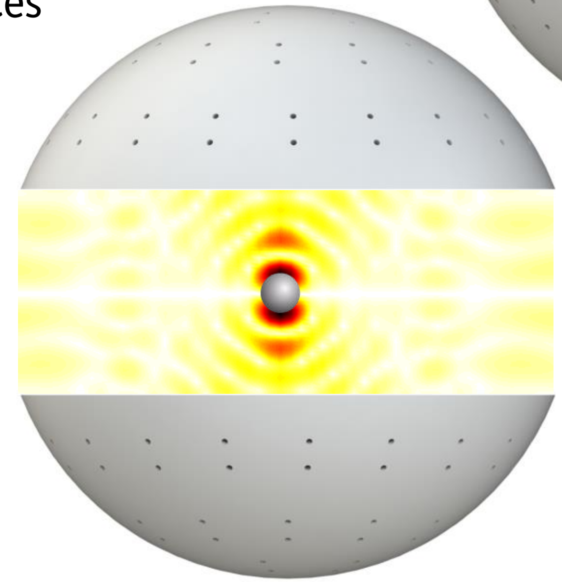
▶ Focussing Of Acoustic Pressure

- Constructive Superposition of the Pressures of Single Transducers at the Focal Point
- Phase φ of Transducer j
- $\varphi_j = -\angle\left(\frac{P_0}{d_\mathrm{d}} e^{i\frac{2\pi f d_\mathrm{d}}{c_0}} + R\frac{P_0}{d_r} e^{i\frac{2\pi f d_r}{c_0}}\right)$, $R = 0$ without Reflective Surfaces



▶ Acoustic Traps

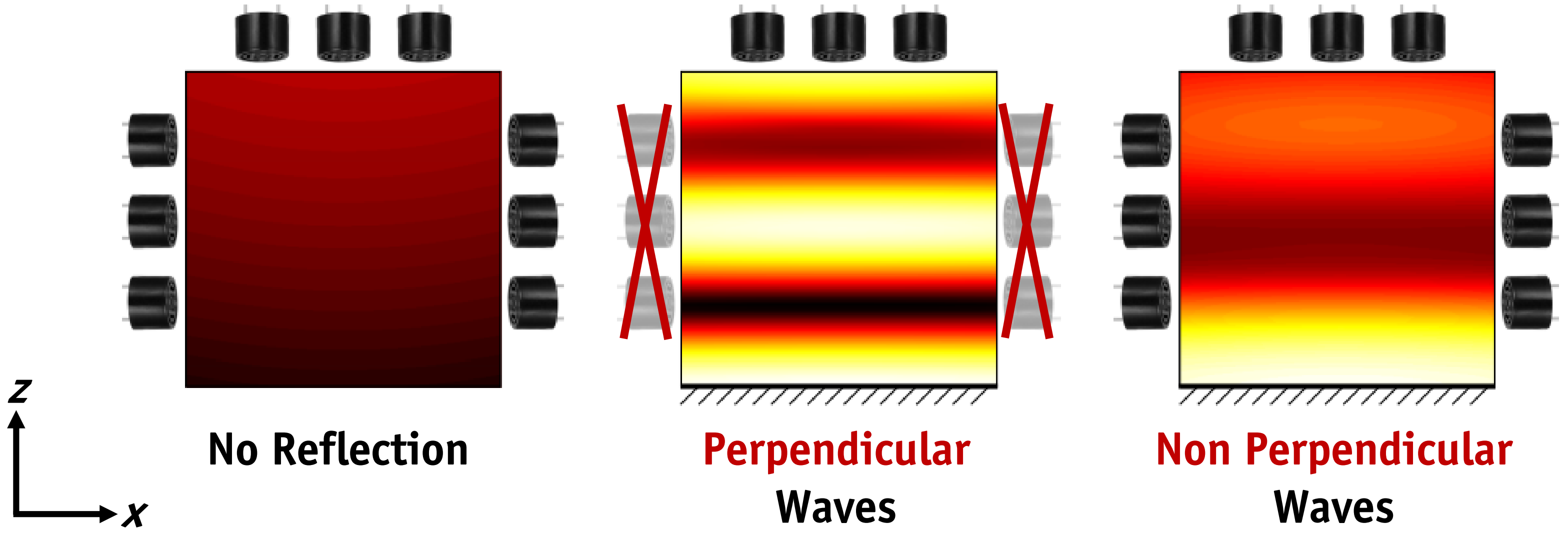
- Adding a Phase Signature to the Phases for Focussing
- 180° Phase Shift for one Half of the Transducers for Twin Traps
  - Horizontal Seperation Plane Between the Halves → HTT
  - Vertical Seperation Plane → VTT



Operating Principle

Reflective Surfaces

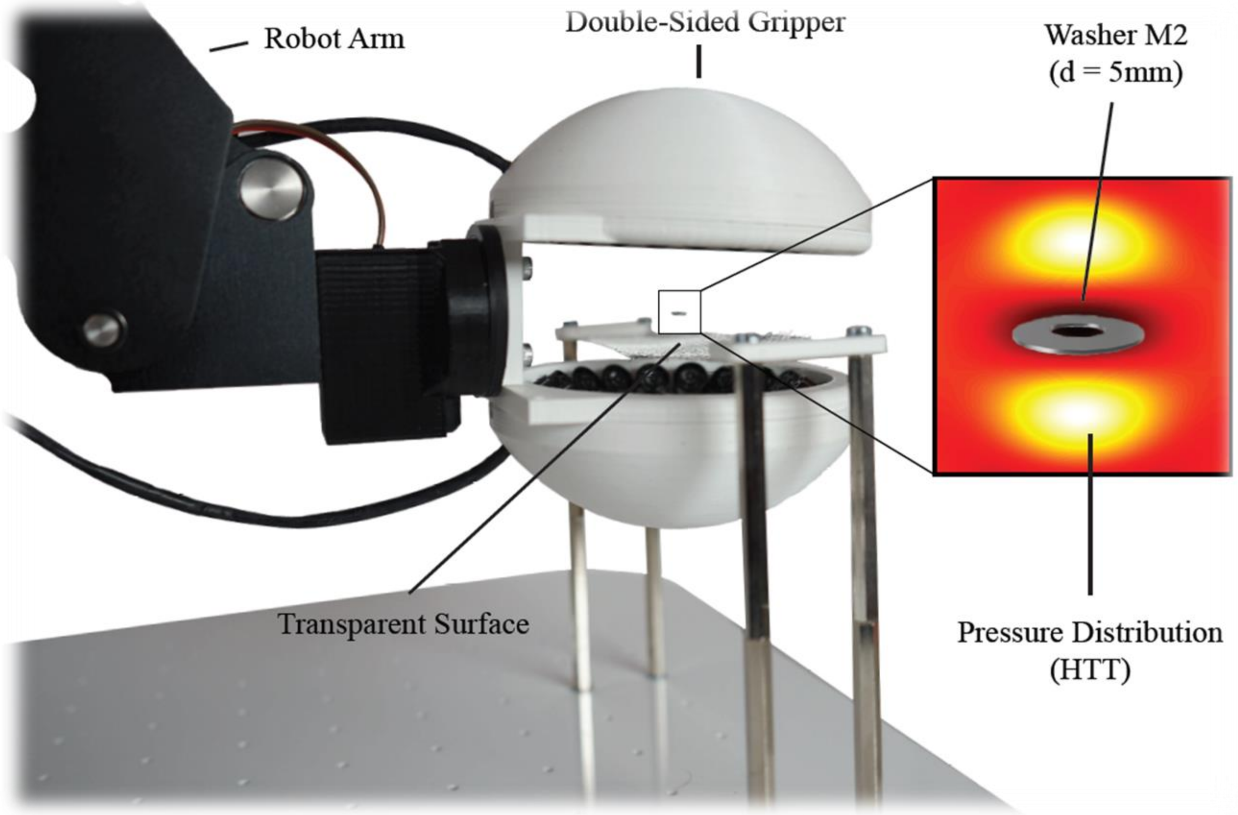
- **Reflection on Acoustically Reflective Surfaces**
  - Perpendicular Arriving Waves → Destructive Superposition $z = \lambda/4$
  - Non Perpendicular → Destructive Superposition Deviates from $\lambda/4$
- **Distribution of Maximum Attainable Pressure (DMAP)**



- **No Focussing** of the Acoustic Pressure Possible in the Surroundings of the Minimum in the DMAP
- **No Vertical Twin Traps**

Picking Process

Double-Sided Gripper



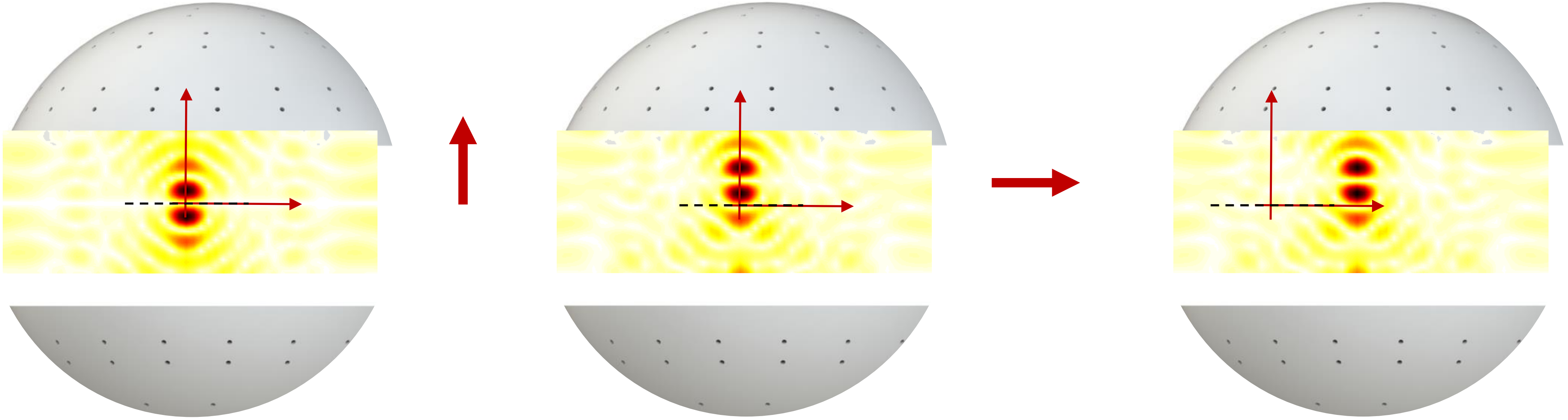
- **Arrangement**
  - 72 Piezoelectric Transducers
  - Arranged on the Two Pole Caps of a Sphere
  - Oriented Towards the Center
- **Control**
  - Square Wave Excitation Signals
  - Individual Phase and Duty Cycle for Each Transducer

Picking Process

Double-Sided Picking

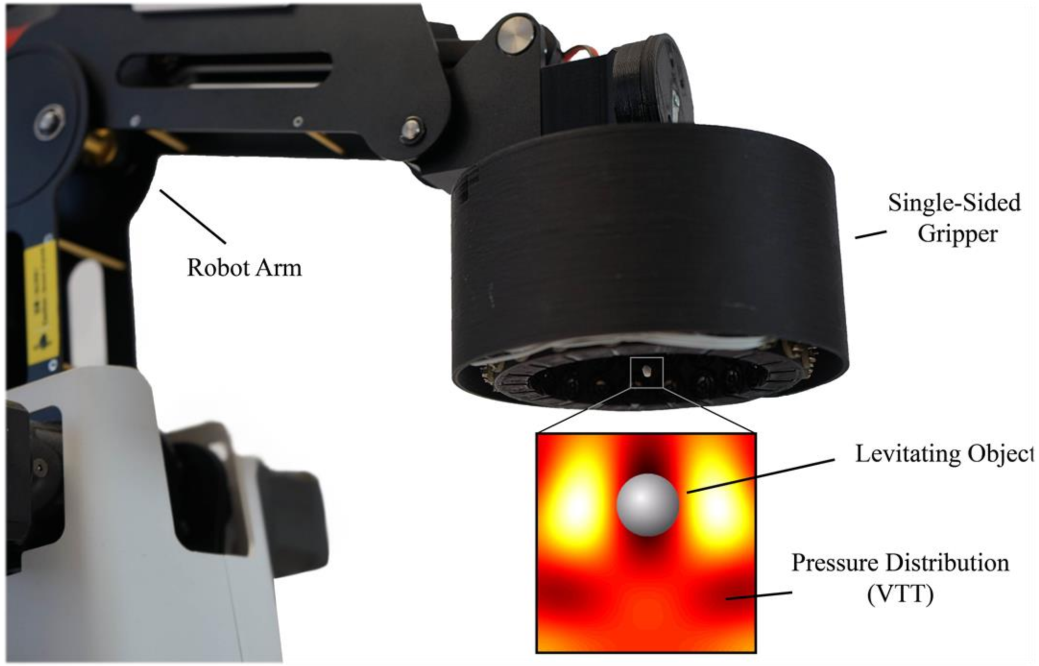
- **Picking Objects from Acoustically Transparent Surfaces**
  - Transmission Coefficient **T > 50 %**

- **Trap Object in VTT**
- **Move Object Vertically**
- **Move Gripper Horizontally**



Picking Process

Single-Sided Gripper

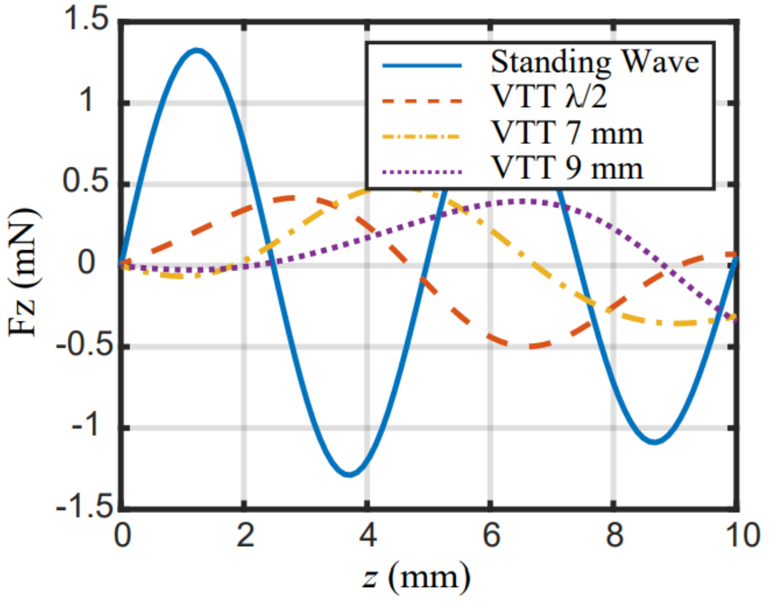


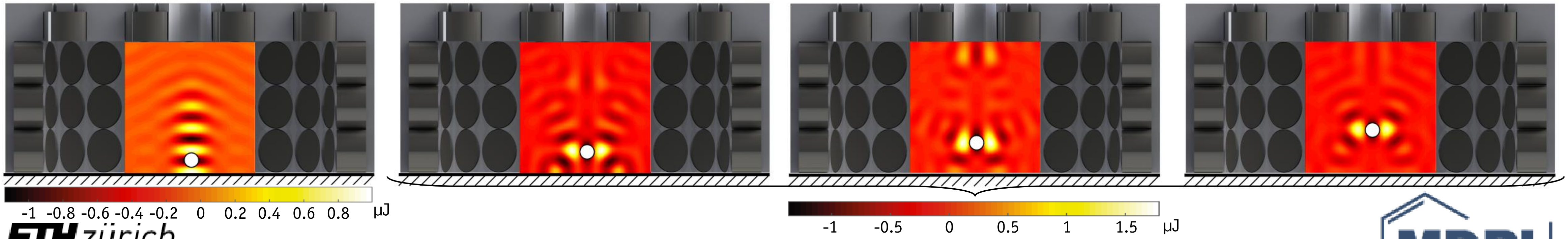
- **Arrangement**
  - 96 Piezoelectric Tranducers
  - Cylindrical Shape
    - 3 Rings of 20 Transducers on the Side Walls
    - 3 Rings of 6, 12, and 18 Transducers on the Horizontal Top
- **Control**
  - Square Wave Excitation Signals
  - Individual Phase and Duty Cycle for Each Transducer

Picking Process

Single-Sided Picking

- **Picking Objects from Acoustically Reflective Surfaces**
  - Transmission Coefficient **T < 50 %**
- **Standing Wave**
  - Lifts the Object off the Surface to $z = \lambda/4$
- **Switch to Vertical Twin Trap at $z = \lambda/2$**
  - Focusing of Pressure Possible for $z \geq \lambda/2$
  - Pulls the Object from $z = \lambda/4$ Into the Acoustic Trap
  - Move VTT Vertically Until Reflections are Negligible





Experimental Results

Automated Insertion of Objects

► **Demonstrated Picking of**

	Diameter	Density	Weight	Reflective Surface	Transparent Surface
Styrofoam Sphere	$d = 4\ \mathrm{mm}$	$0.04\ \mathrm{g/cm^3}$	$1.3\ \mathrm{mg}$	✓	✓
Pyrobubble Sphere (SiO_2)	$d = 4\ \mathrm{mm}$	$0.25\ \mathrm{g/cm^3}$	$8.4\ \mathrm{mg}$	✓	✓
Steel Sphere	$d = 3\ \mathrm{mm}$	$7.8\ \mathrm{g/cm^3}$	$110\ \mathrm{mg}$	✗	✓
Steel Washer	$d = 5\ \mathrm{mm}$	$7.8\ \mathrm{g/cm^3}$	$37.1\ \mathrm{mg}$	✗	✓

► **Limitations Reflective Surfaces**

- High Vertical Forces Using Standing Waves
- VTTs Provide Limited Vertical Forces

$\rightarrow d < \mathbf{4\ mm}, \rho < \mathbf{0.25\ g/cm^3}$

Conclusion

- **Demonstrated Control Concepts for the Automation of Gripping Objects Acoustically**
  - For Objects with a Density of up to $7.8\ \mathrm{g/cm^3}$
  - Located on Acoustically Transparent or Reflective Surfaces
  - For Minimized Stress During the Lift Off Process
- **Further Improvements of the Single-Sided Picking Process**
  - Using Transducer which Produce High Pressure for a Wider Range of Frequencies
  - Pick Objects with a Higher Density from Reflective Surfaces
  - Opens Up Even More Fields of Application

Thank You !