Contactless Manipulation with Airflow: from Macro to Micro Devices

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Contactless manipulation with airflow

Manipulation with airflow

Aerostatic

Bernoulli

Aerodynamic
Aerostatic manipulation systems
Outline

- Air flow manipulators
- Physical modeling
- Control methods
- Conclusion and current work
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Tilted air jet systems

3-DOF Paper Mover
- 1152 controlled air jets
- 25 linear CMOS sensor bars
- Speed 30mm/s
- Precision 25μm

Xerox Palo Alto Research Center
[Berlin, 2000]

3-DOF Wafer Positioner
- Precision 3μm (with edge sensors)
- Precision 10nm (with optical encoders)

Delft University of Technology
[Wesselingh, 2009]
Tilted air jets microsystems

**MEMS Array**
560 integrated electrostatic valves
LIMMS/IIS, Tokyo
[Fukuta, 2006]

**2-DOF Microconveyor**
4 networks of tilted air jets
Max. speed 137mm/s
Precision 18µm (feedback control)
FEMTO-ST, Besançon
[Zeggari, 2010] [Laurent, 2014]
Potential air flow manipulators

3-DOF Passive Positioner
- Air cushion for levitation
- Suction hoses for transport
- Proof of stable equilibrium
University of Michigan, Ann Arbor
[Moon, 2006]

3-DOF Active Positioner
- Air cushion for levitation
- Induced air flow for transport
- Max. speed 200 mm/s
FEMTO-ST, Besançon
[Laurent, 2011]
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Physical modeling

Potential flow theory
[Moon, 2006]

\[ F_{D_1} = \int \int_S U(x, y) \, dx \, dy \]

Object dynamic

\[ m \frac{dV}{dt} = \sum F \]

Drag force

\[ F_{D_2} = \frac{1}{2} \rho C_d A V^2 \]

Couette's flow
[Toda, 1997]

\[ F_{D_3} = \frac{\mu S}{h} V \]

Tilted air jet
[Toda, 1997]

\[ F_P = \frac{1}{2} \rho C_P \frac{q_e^2}{a} \sin \theta \]

Aerostatic lift force
[McDonald, 2000]

\[ F_L = \frac{3\mu q_e S}{\pi h^3} \]
Could we levitate micro-objects?

- Downsizing air bearings

- Aerostatic lift force = weight

\[ q_e = \frac{g \rho \pi}{3 \mu} h^4 \]
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Model structure

- For all systems, the force and moment applied to the object can be written as:

\[
\begin{bmatrix}
F_x \\
F_y \\
\Gamma
\end{bmatrix} = \begin{bmatrix}
m_{11} & m_{12} & \cdots & m_{1n} \\
m_{21} & m_{22} & \cdots & m_{2n} \\
m_{31} & m_{32} & \cdots & m_{3n}
\end{bmatrix} \begin{bmatrix}
q_1 \\
q_2 \\
\vdots \\
q_n
\end{bmatrix} = M.Q
\]

where
- \( m_{i,j} \) are the interaction coefficients depending on the object position (non linear functions)
- \( q_i \) are the volumetric flow of each jet

- Object dynamics:

\[
m \ddot{x} = F_x - \lambda \dot{x}
\]
Inverse modeling control (centralized)

- Inversion of $M$ (redundancy)
  - Hierarchical force allocator [Jackson, 2001]
  - Heuristic [Wesselingh, 2010]
  - Linear programming [Delettre, 2012] (minimization of flow)
Decentralized control by reinforcement learning

- Decentralized -> Independent learners (not markovian)
- Soan algorithm = $Q(I) +$ coordination heuristic [Matignon, 2010]
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Conclusion

- **Performances**
  - Contactless
  - Heavy objects
  - High speed (m/s)
  - High precision (10nm)

- **Constraints**
  - Object size > 1mm
  - Flat underneath surface

- **Semiconductor industry**
  - Handling of larger and thinner wafers
  - High speed transport of solar cells

Wafers on the conveyor (wikimedia)
Current works

- Design of conveyor for fast transport of wafer/solar cells

- Modular system
  - Unidirectional blocks
  - Flexible (positioner, conveyor, ...)
  - Decentralized control at the blocks level

- Block design
  - Size = 75x75 mm
  - Array of tilted air jets (45°)
  - 3D printed
References


