AIM'14 WORKSHOP

Merging micro & macro manipulation and manufacturing technologies and methods

Contactless Manipulation with Airflow: from Macro to Micro Devices

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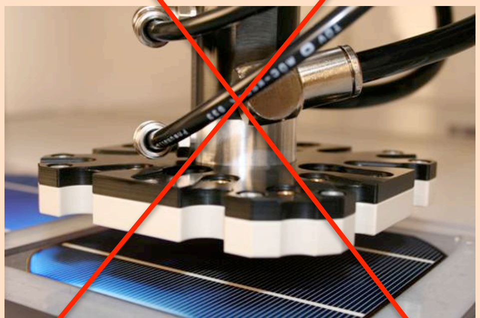
Smart Blocks Project ANR-251-2011-BS03-005

Contactless manipulation with airflow

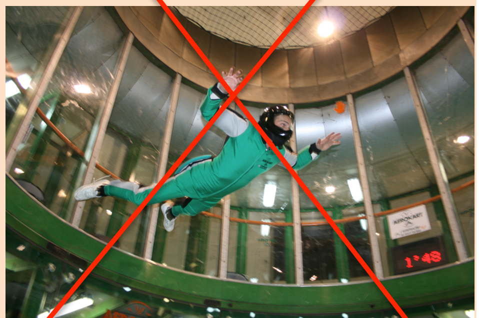
Manipulation with airflow

Aerostatic

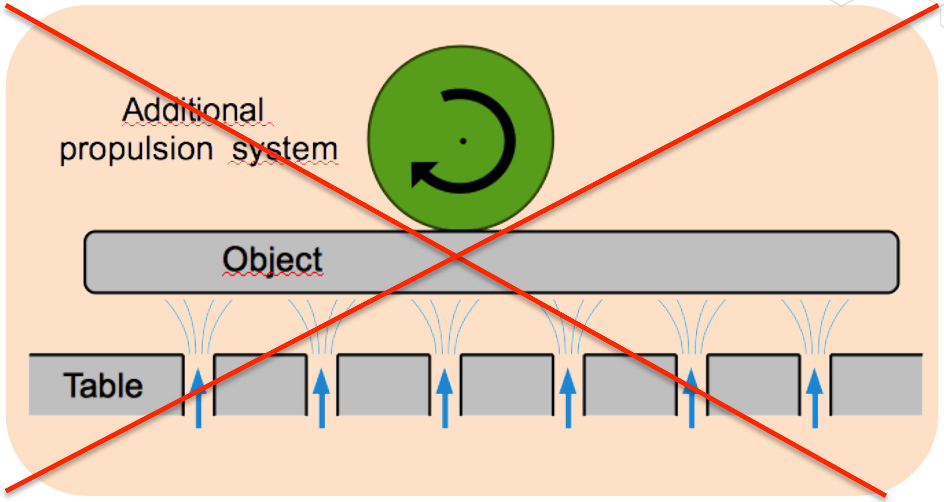
Bernoulli

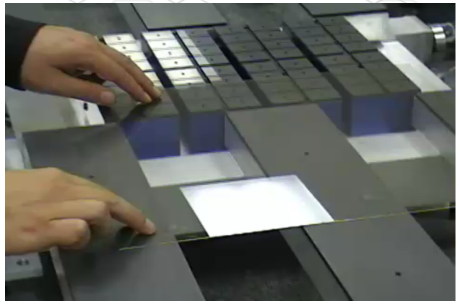


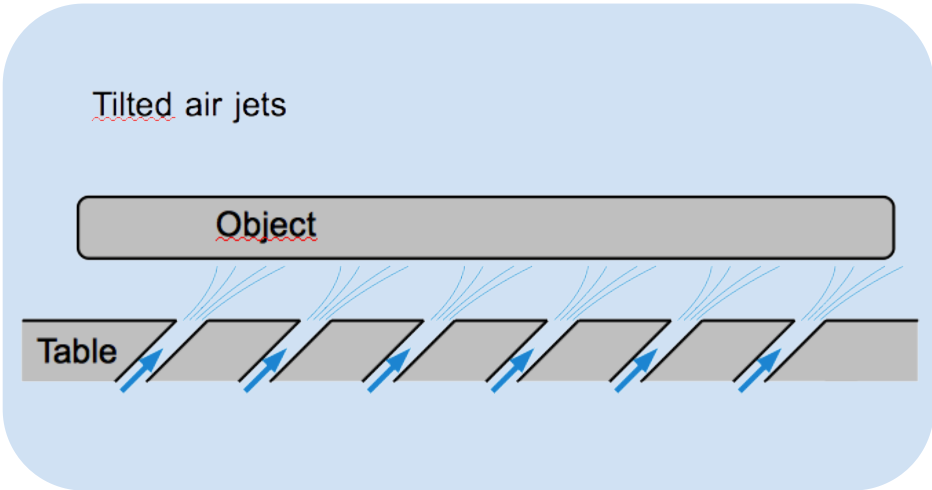
Aerodynamic

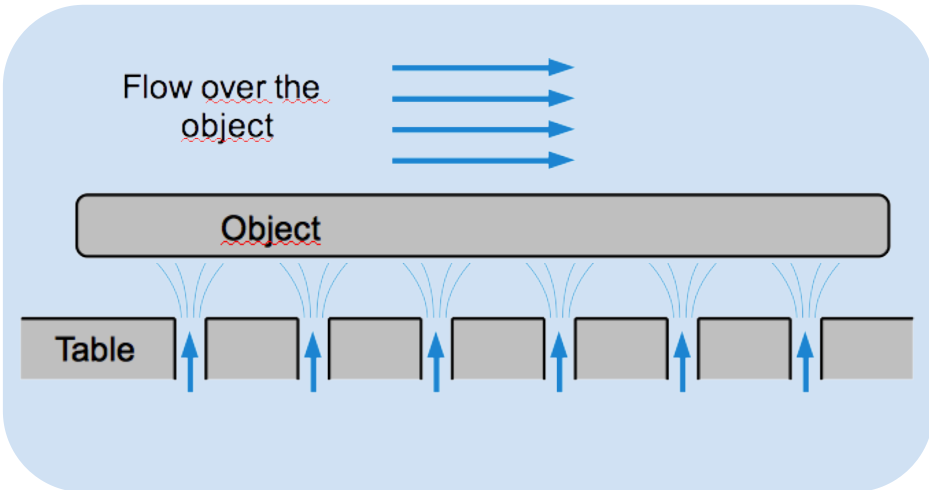


Aerostatic manipulation systems









Outline

- Air flow manipulators
- Physical modeling
- Control methods
- Conclusion and current work

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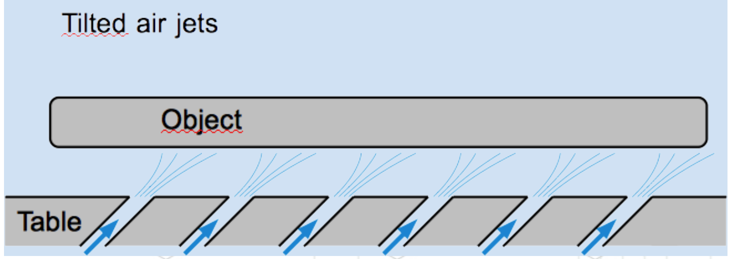
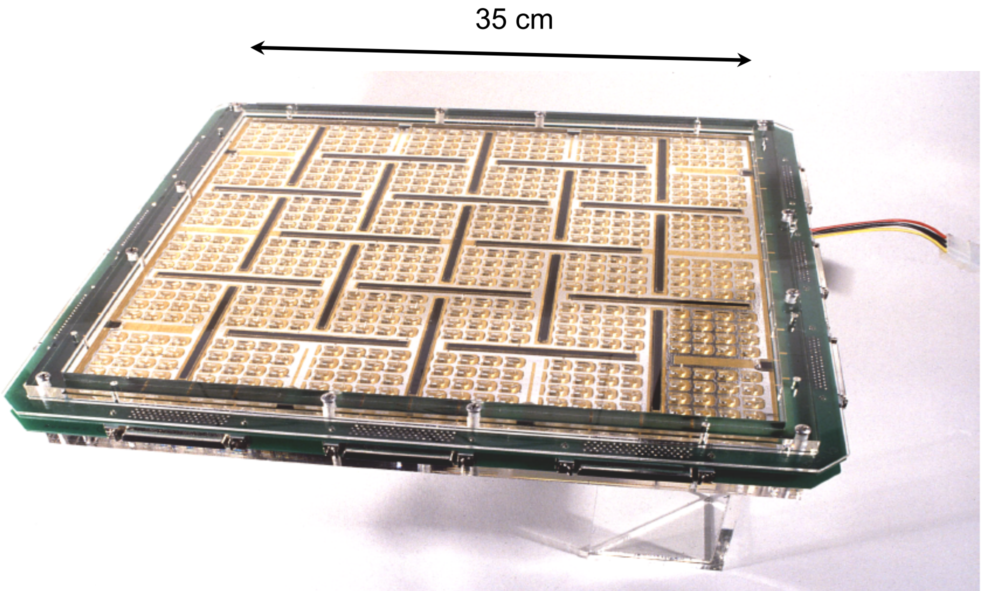
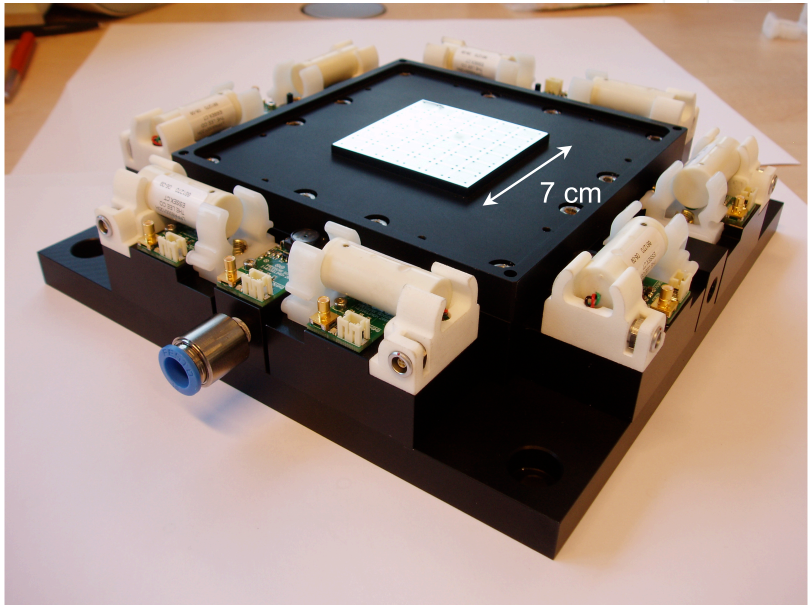
Tilted air jet systems



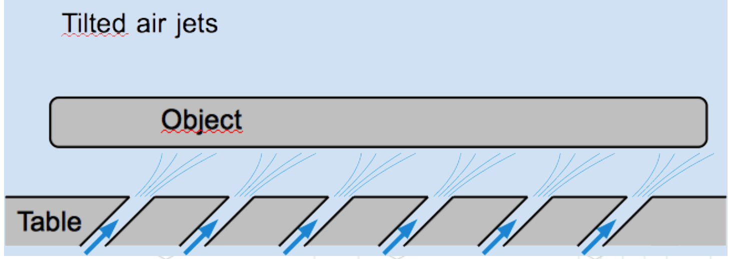


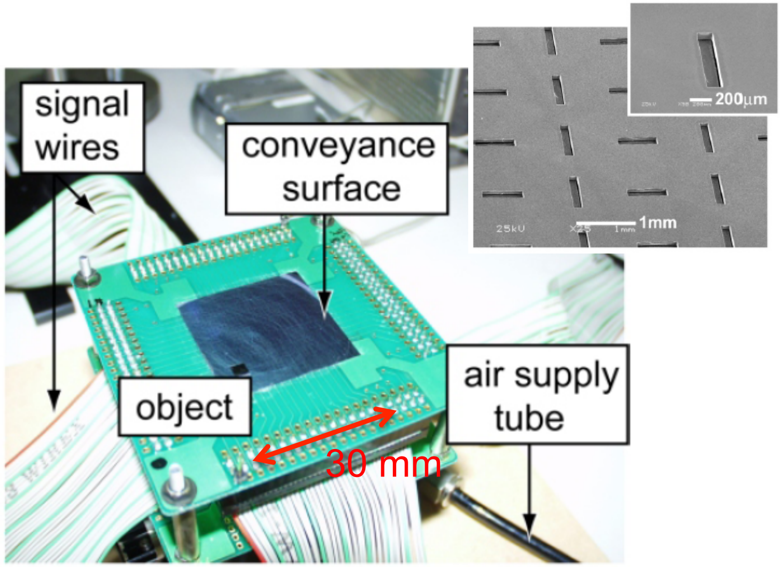
3-DOF Paper Mover
1152 controlled air jets
25 linear CMOS sensor bars
Speed 30mm/s
Precision 25µm
Xerox Palo Alto Research Center
[Berlin, 2000]



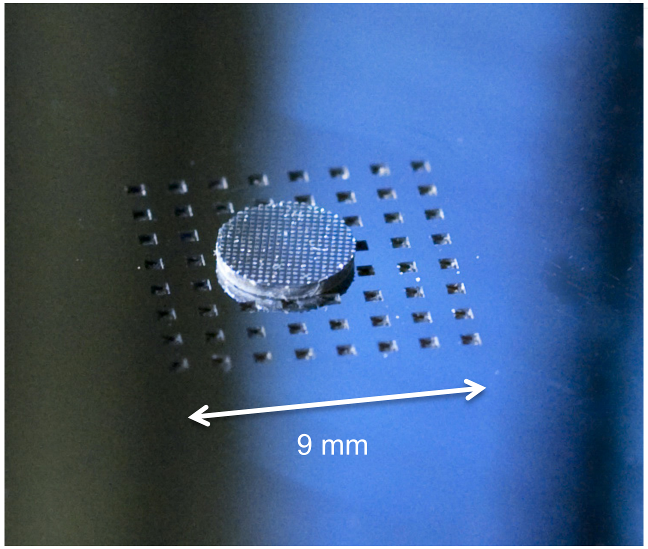
3-DOF Wafer Positioner
Precision 3µm (with edge sensors)
Precision 10nm (with optical encoders)
Delft University of Technology
[Wesselingh, 2009]

Tilted air jets microsystems



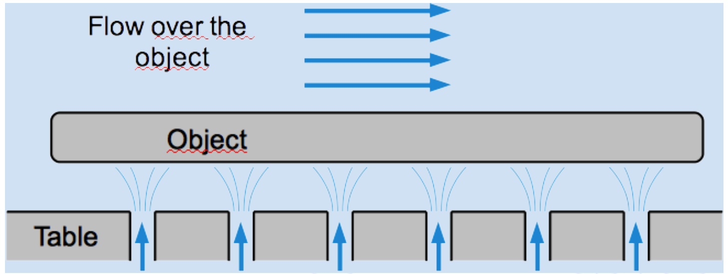


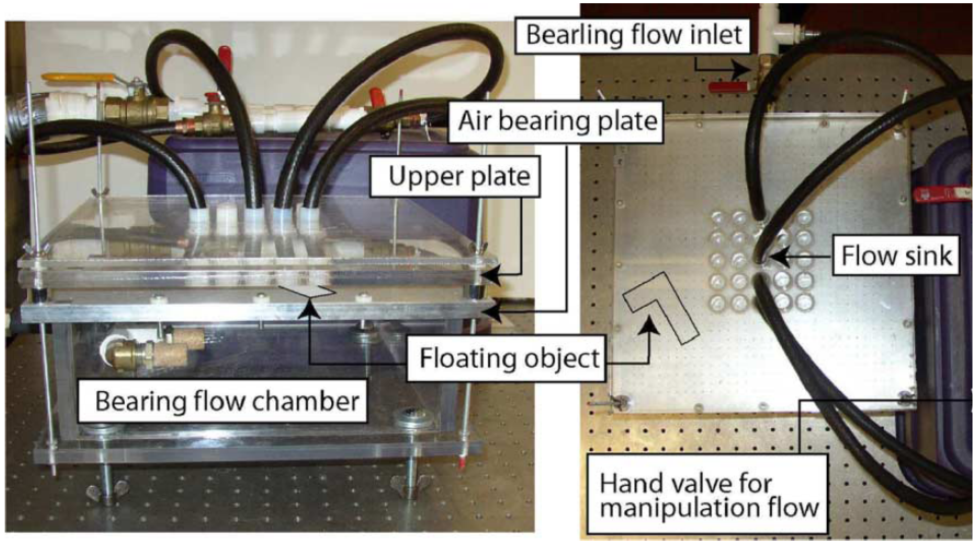
MEMS Array
560 integrated electrostatic valves
LIMMS/IIS, Tokyo
[Fukuta, 2006]

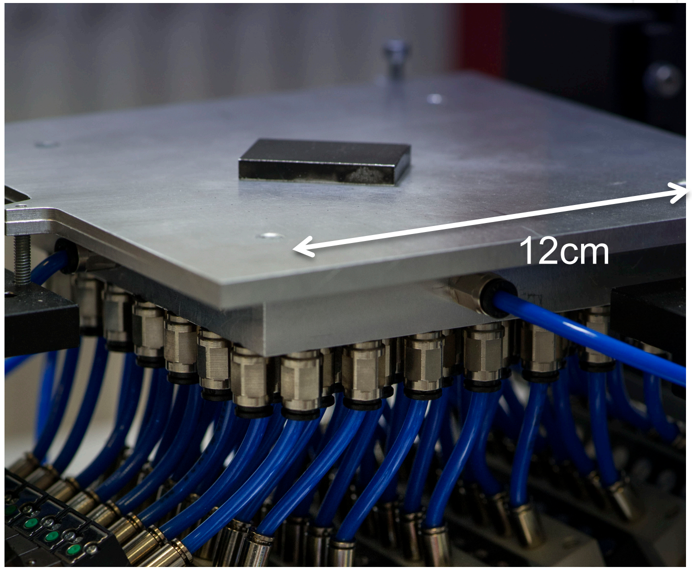


2-DOF Microconveyor
4 networks of tilted air jets
Max. speed 137mm/s
Precision 18µm (feedback control)
FEMTO-ST, Besançon
[Zeggari, 2010] [Laurent, 2014]

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 200mm/s
FEMTO-ST, Besançon
[Laurent, 2011]

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Physical modeling

Potential flow theory
[Moon, 2006]

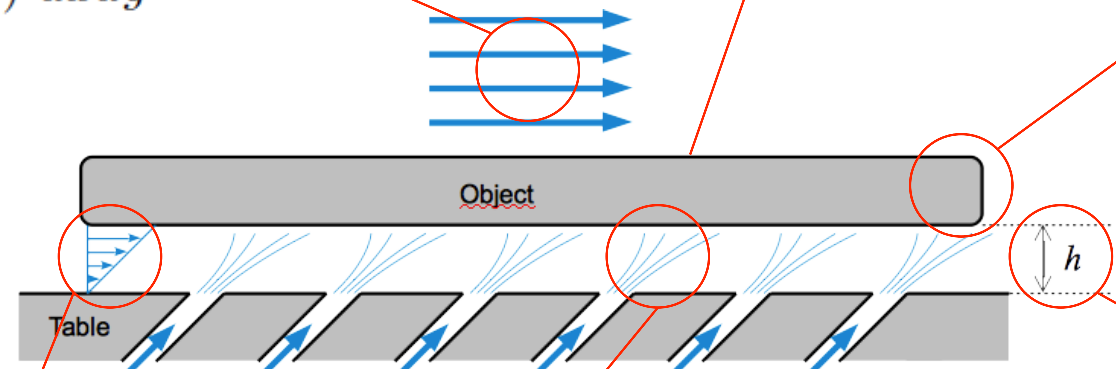
$$F_{D_1} = \iint_S U(x,y)\ dxdy$$

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]

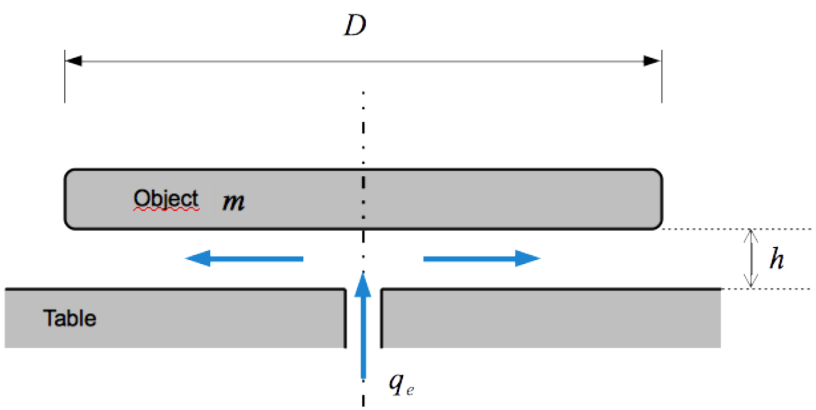
$$F_P = \frac{1}{2}\rho C_P \frac{q_e^2}{a}\sin\theta$$

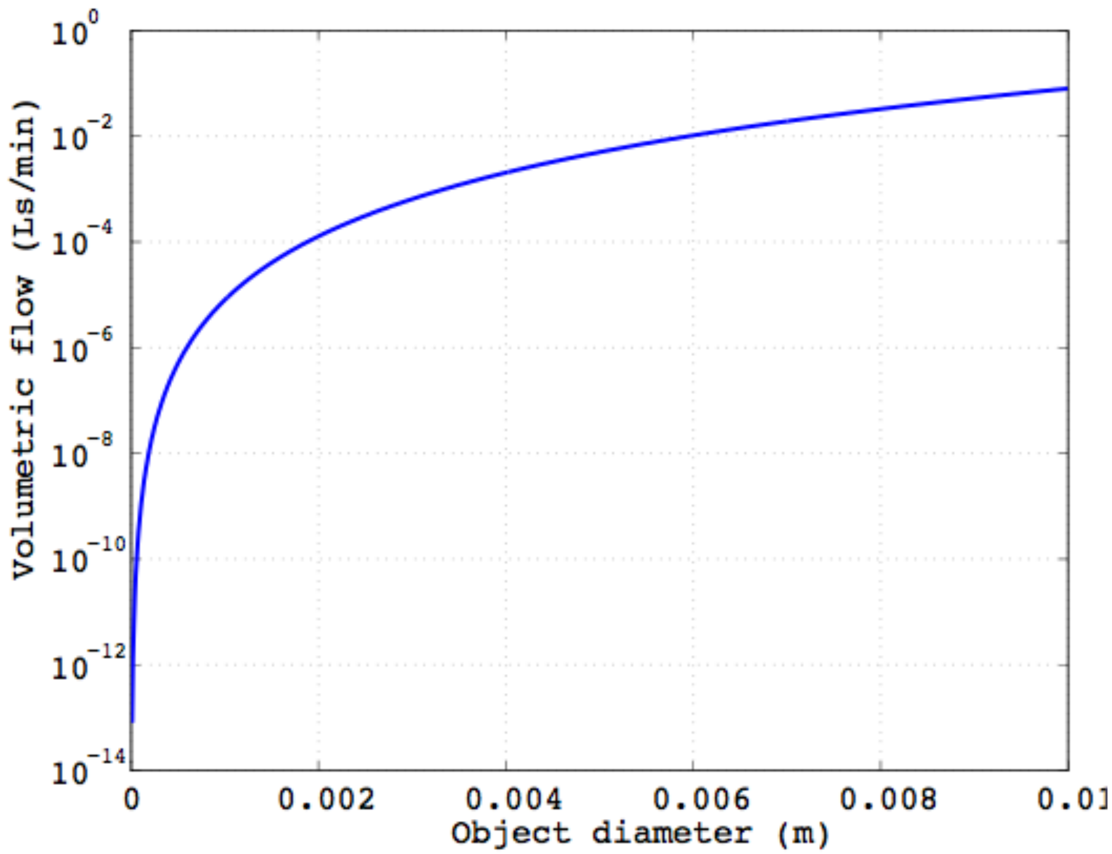
Aerostatic lift
force
[McDonald, 2000]

$$F_L = \frac{3\mu q_e S}{\pi h^3}$$

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:

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

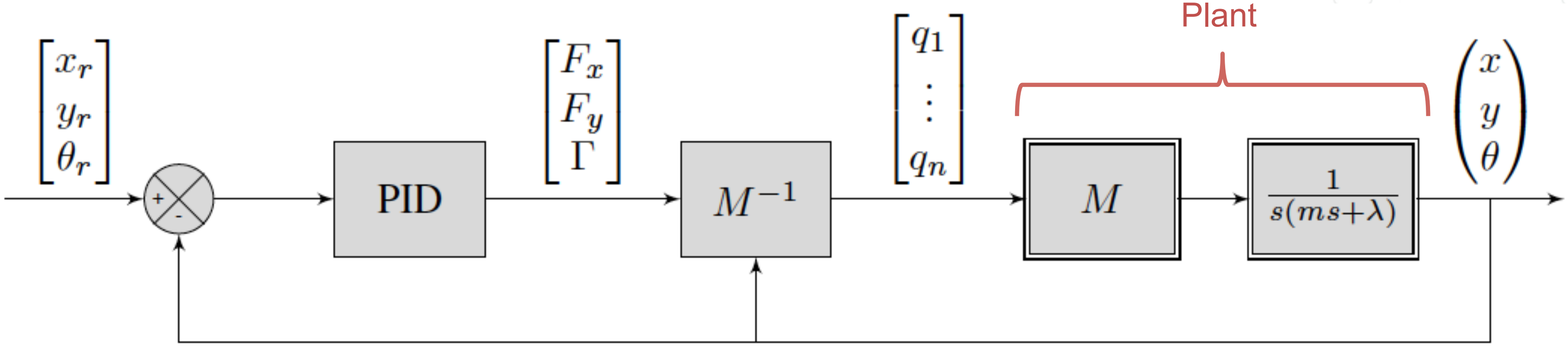
where

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

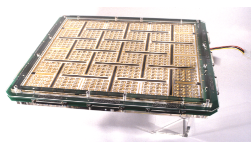
- Object dynamics:

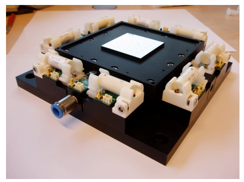
$$m\,\ddot{x} = F_x - \lambda\,\dot{x}$$

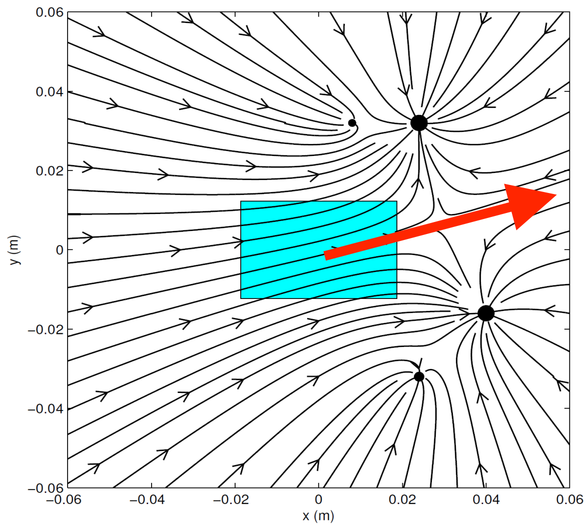
Inverse modeling control (centralized)



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

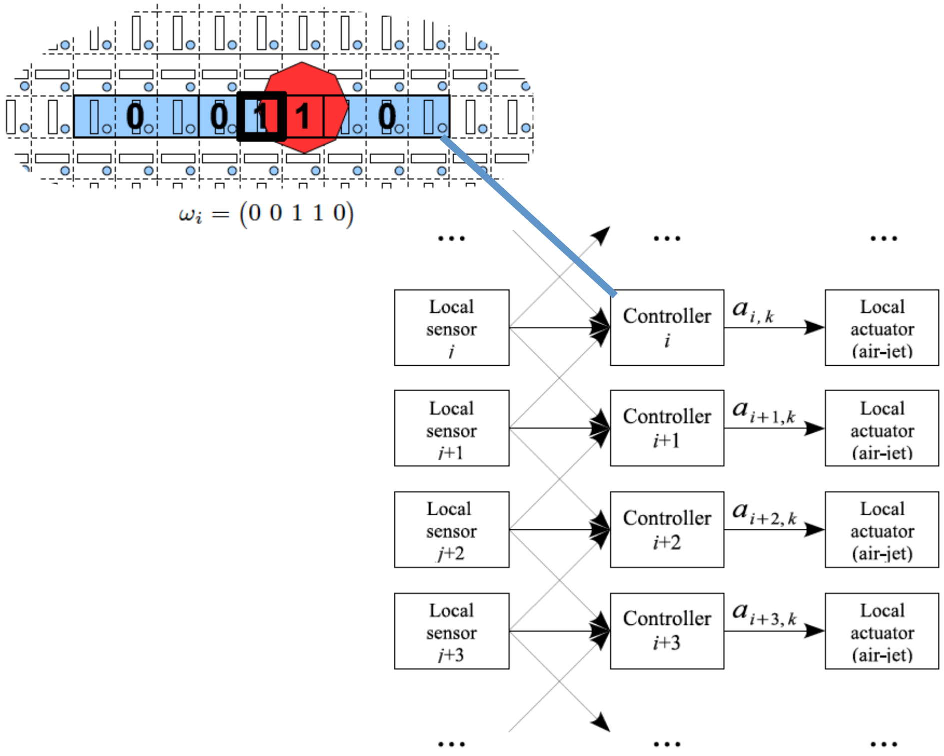


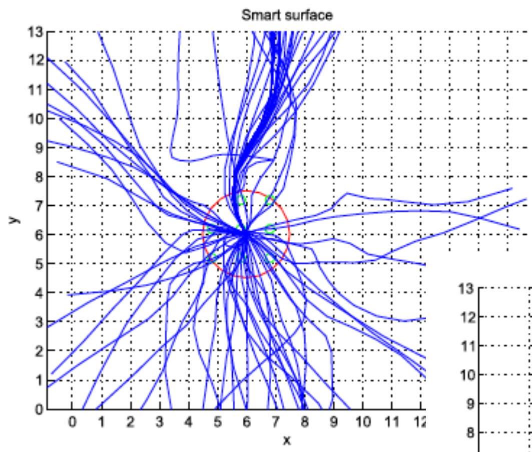




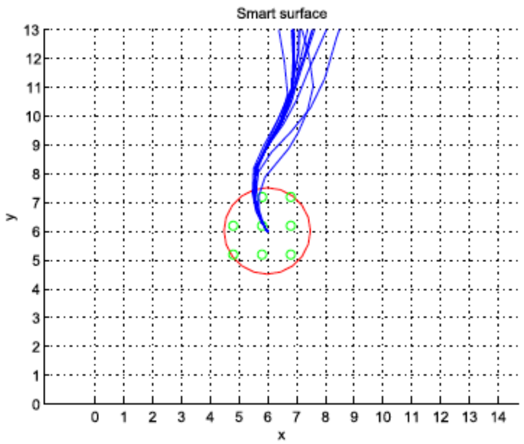
Decentralized control by reinforcement learning

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





(a) episode 1 to 100



(d) episode 301 to 400

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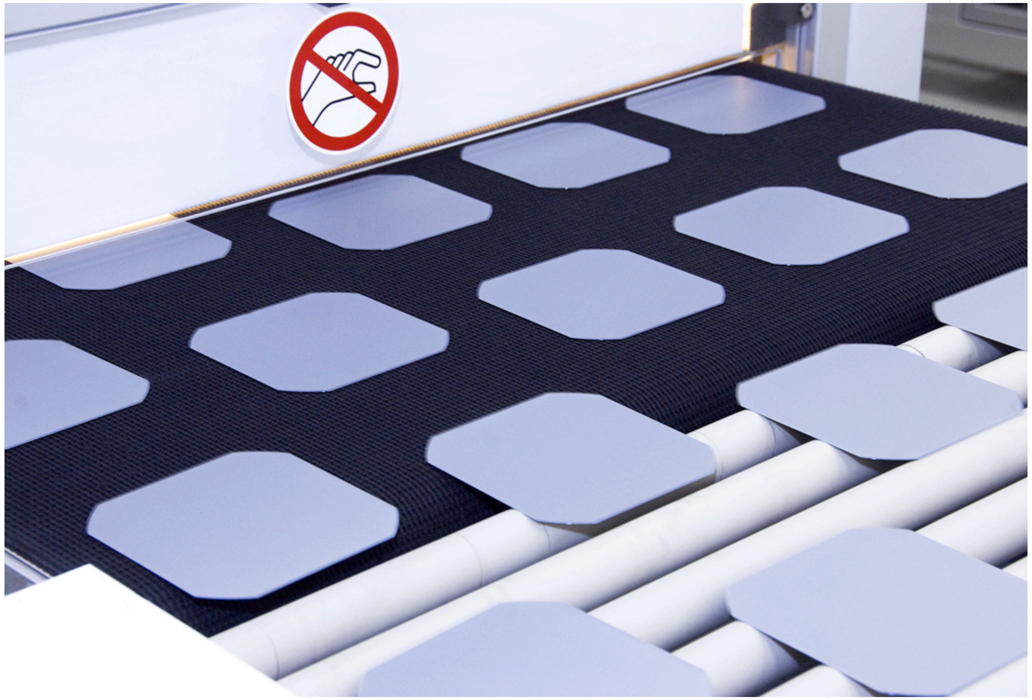
Conclusion

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

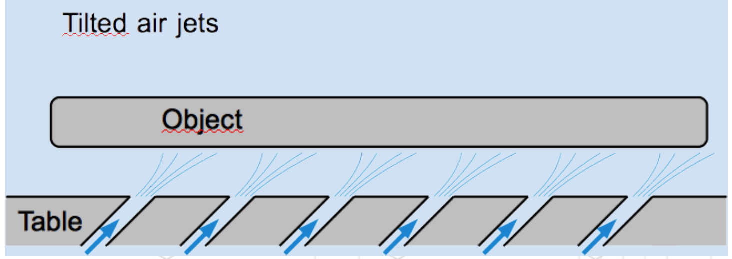
- **Constraints**
  - Object size > 1mm
  - Flat underneath surface

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

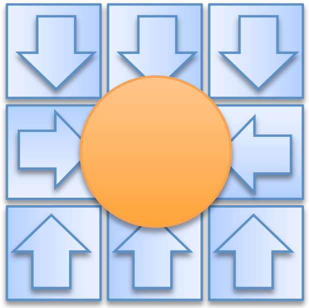


Wafers on the conveyor (wikimedia)

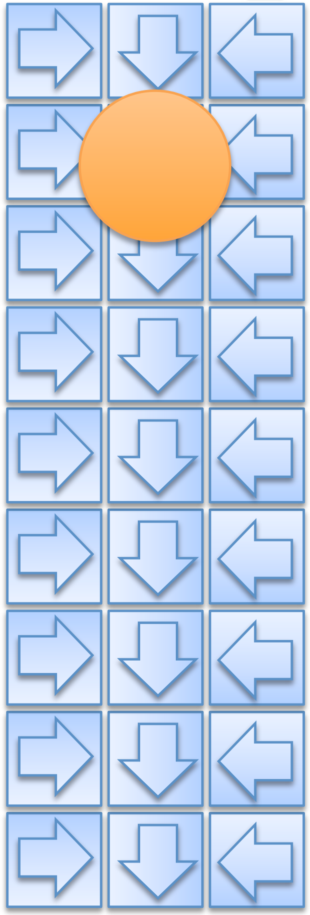
Current works



- 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

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