SAPIENZA
UNIVERSITÀ DI ROMA

Collision in Human Robot Collaboration

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SAPHARI
SAFE AND AUTONOMOUS PHYSICAL HUMAN-AWARE ROBOT INTERACTION


Safety
Coexistence
Collaboration

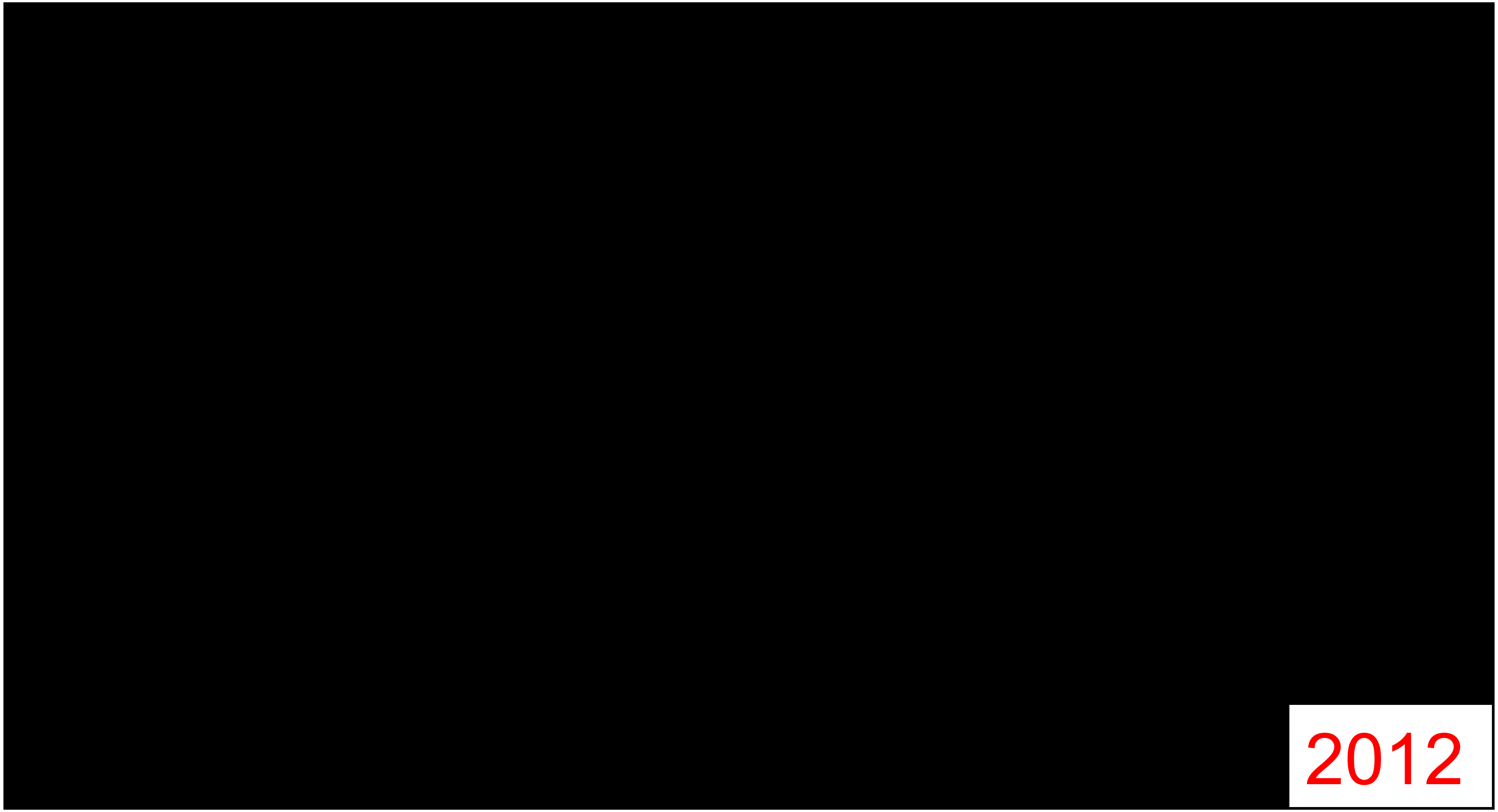
Coexistence

YESTERDAY

1989

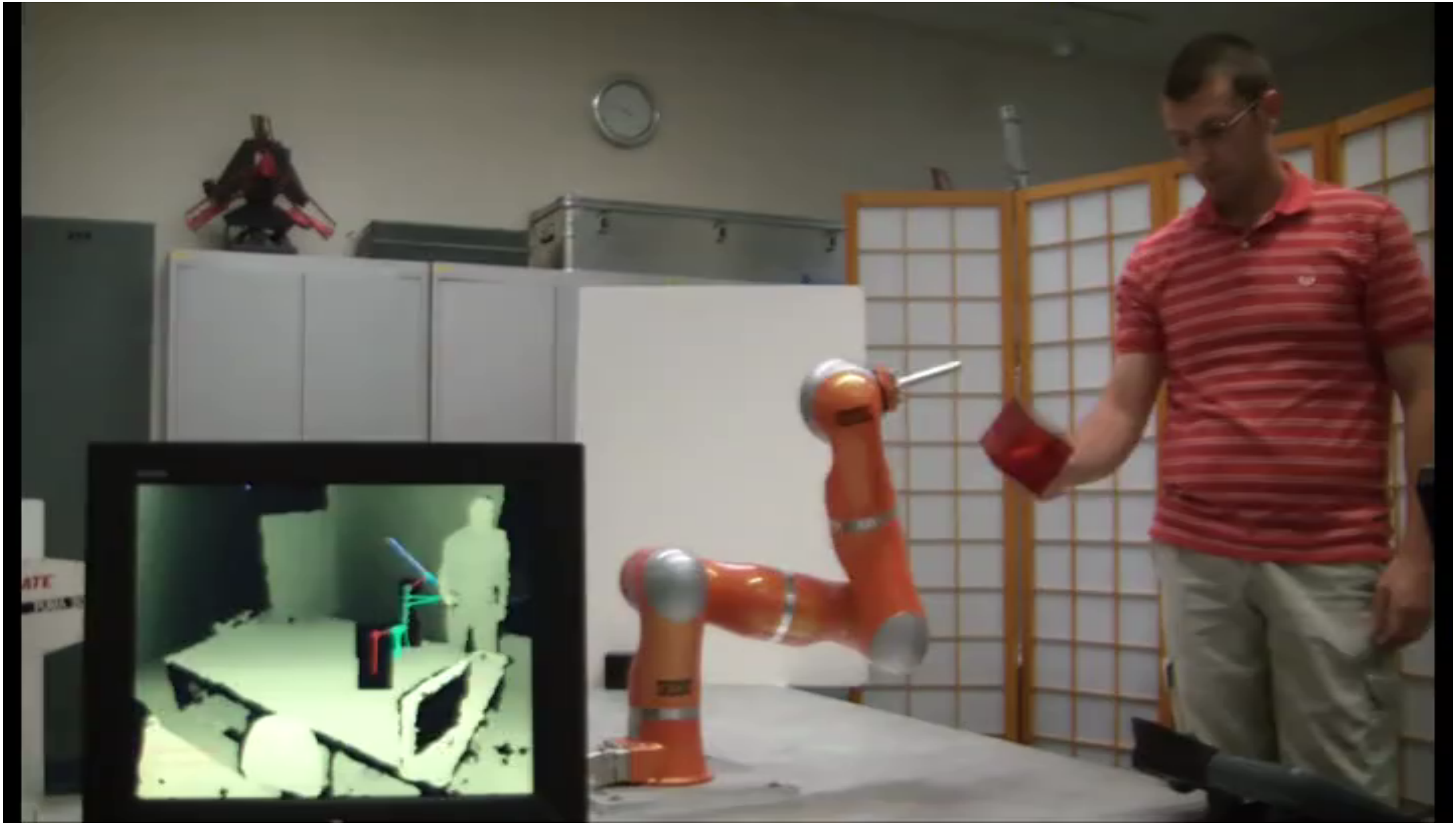
Coexistence

TODAY



Coexistence

TOMORROW



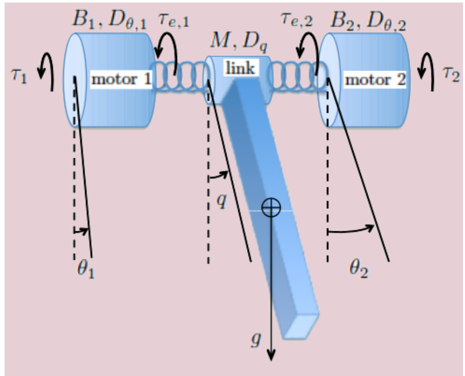
Safety

Top-down hierarchy

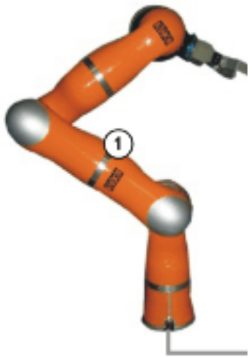
Collision avoidance

Physical collision detection

Variable Stiffness Actuator



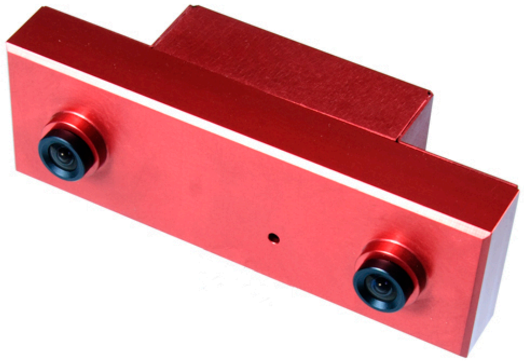
Lightweight and compliant robots



Depth sensors

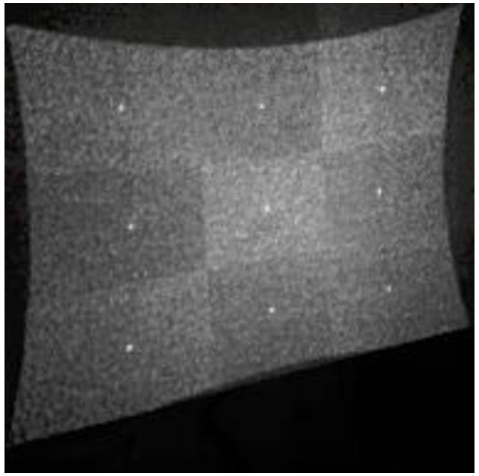
From stereovision to the Kinect

Stereovision



Time of Flight

Structured Light



Depth space

A 2.5 dimensional space

Non-homogeneous 2.5 dimensional space
- x,y position of the point in the image plane (pixel)
- d depth of the point w.r.t. the image plane (m)

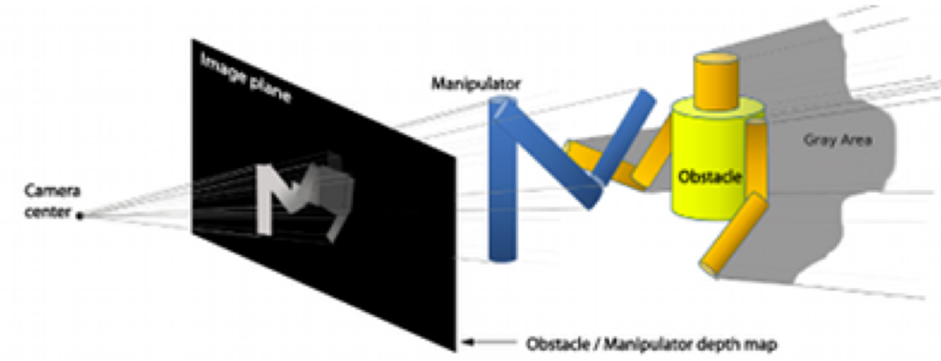
The depth space is modeled as a pin-hole

Point in a Cartesian reference frame $\boldsymbol{P}_R = (x_R, y_R, z_R)$

Point in the sensor frame $\boldsymbol{P}_C = \boldsymbol{R}\boldsymbol{P}_R + t = (x_C, y_C, z_C)$

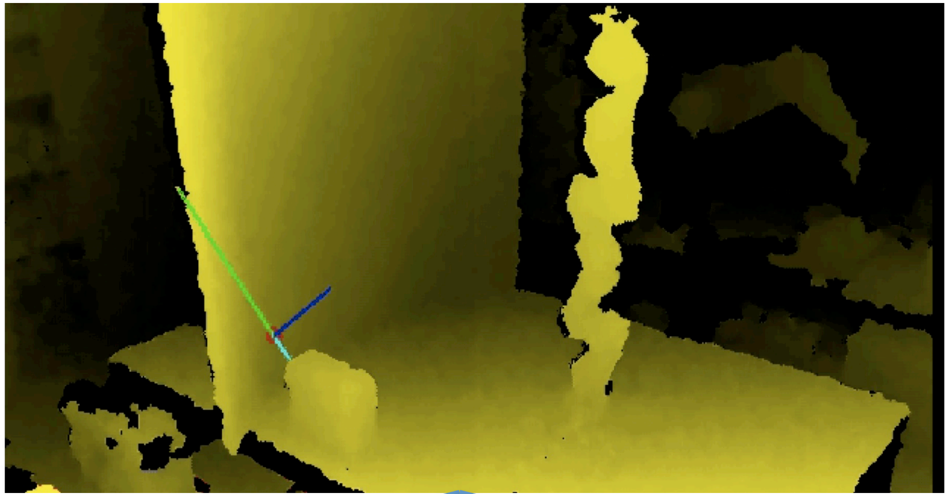
Point in the depth space

$$
\begin{aligned}
p_x &= \frac{x_C f s_x}{z_C} + c_x \\
p_y &= \frac{y_C f s_y}{z_C} + c_y \\
d_p &= z_C
\end{aligned}
$$



Depth Image

How to use it?



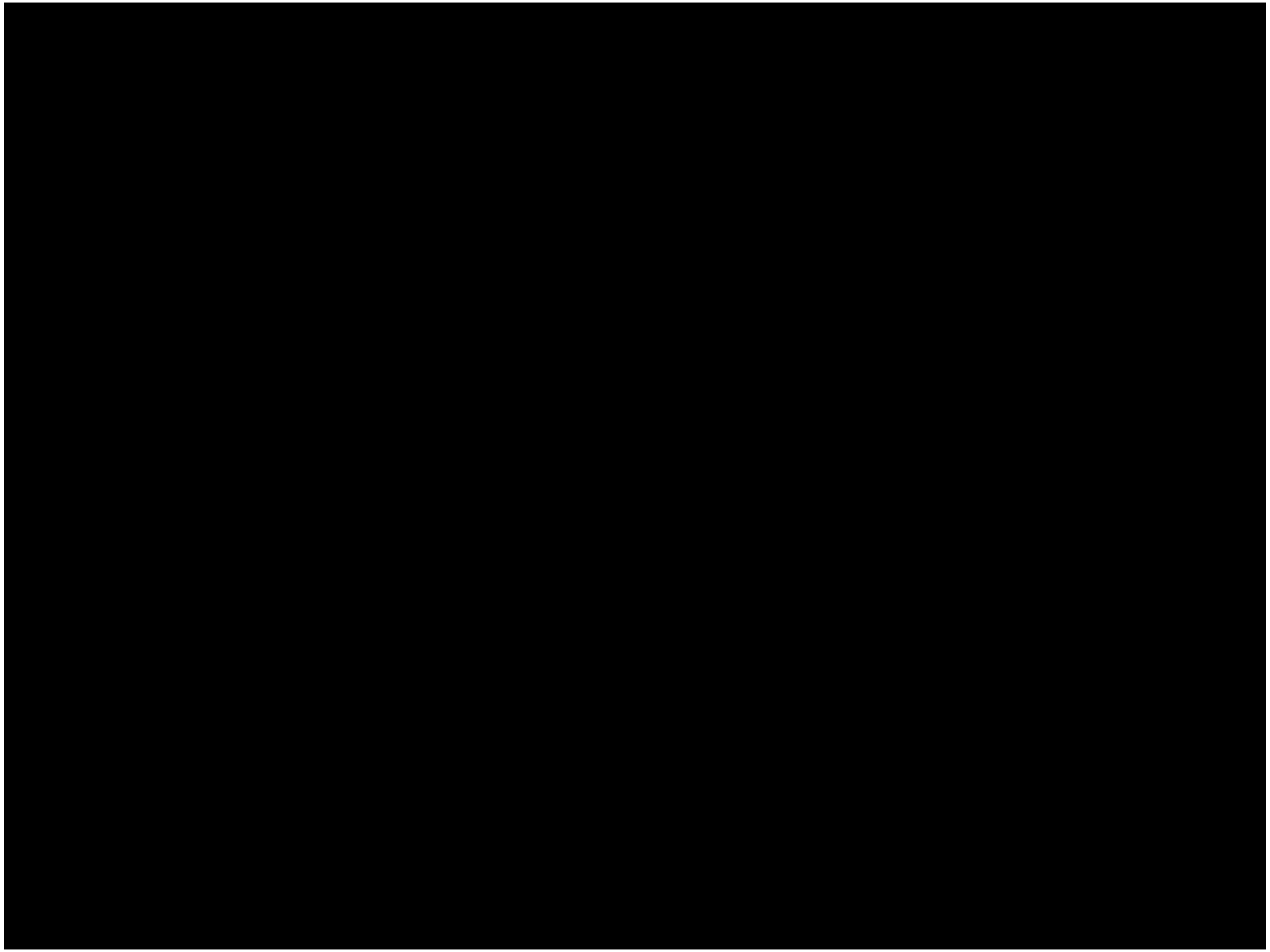
Configuration Space

Cartesian Space

Depth Space

Configuration Space

Only for few dof



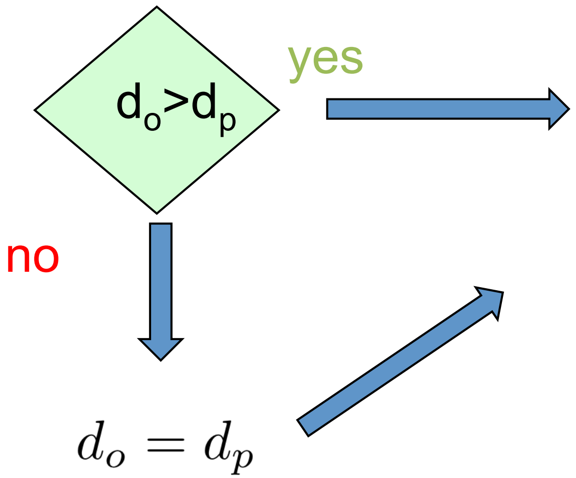
Cartesian Space

A long process

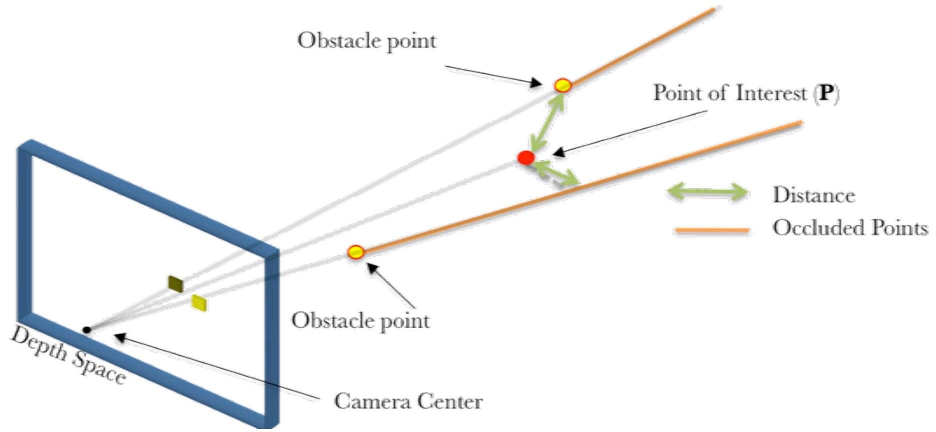
Depth Space

Distance Evaluation

Distance between a point of interest $\boldsymbol{P}_D = (p_x, p_y, d_p)$ and an obstacle point $\mathbf{O}_D = (o_x, o_y, d_o)$

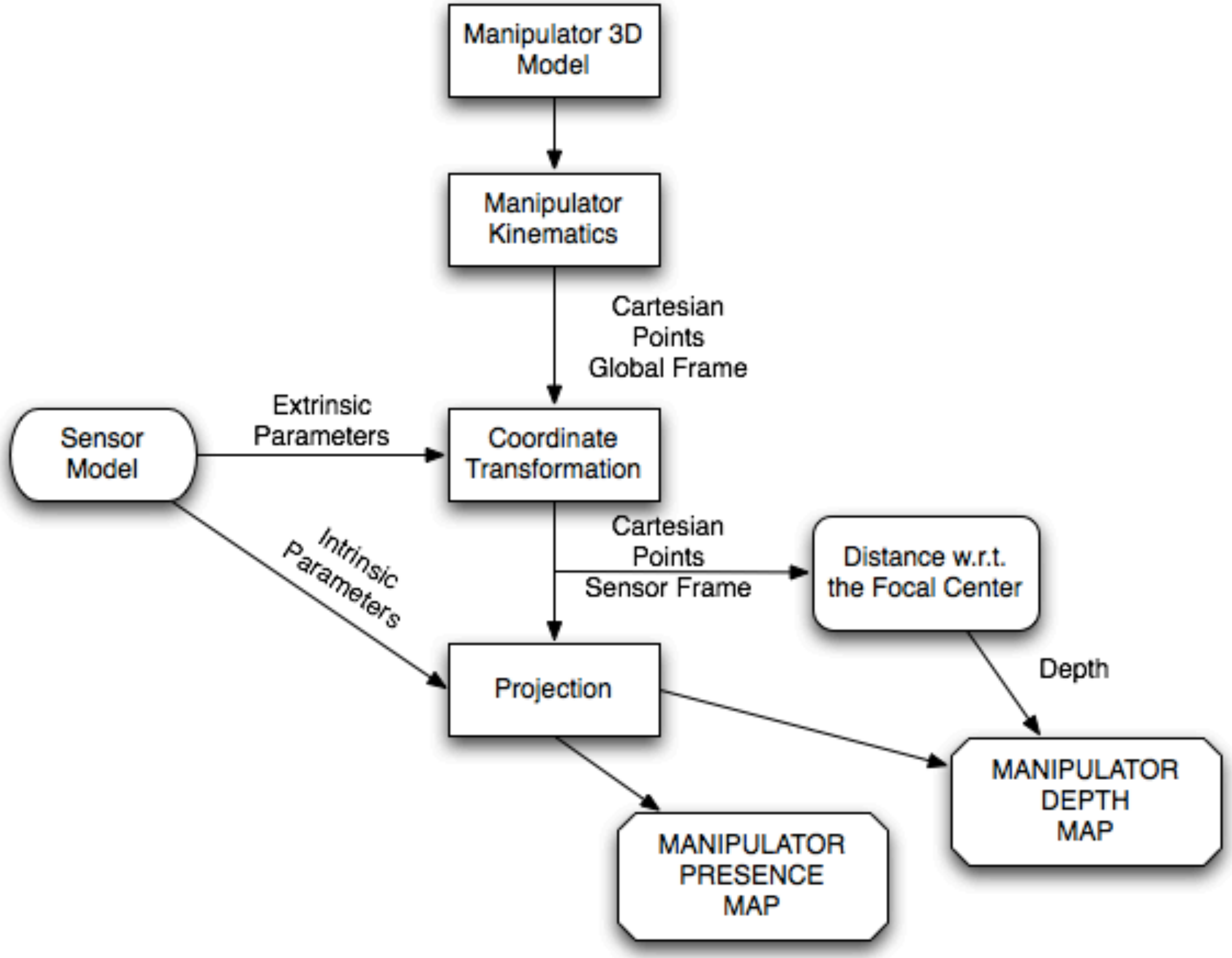


$$
\begin{aligned}
v_x &= \frac{(o_x - c_x)d_o - (p_x - c_x)d_p}{f s_x} \\
v_y &= \frac{(o_y - c_y)d_o - (p_y - c_y)d_p}{f s_y} \\
v_z &= d_o - d_p \\
\mathrm{dist}(\boldsymbol{P}, \mathbf{O}) &= \sqrt{v_x^2 + v_y^2 + v_z^2}
\end{aligned}
$$



Robot Depth Image

All known



Repulsive Vector

A potential field like method

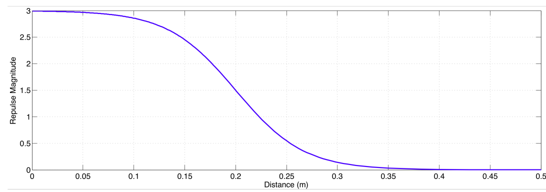
Repulsive vector generated from the distance vector

$$\boldsymbol{D}(\boldsymbol{P}, \mathbf{O}) = (v_x, v_y, v_z)$$

Repulsive vector due to a single obstacle point

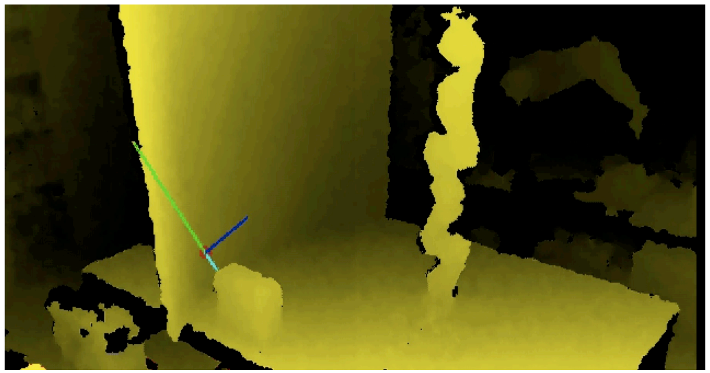
$$\boldsymbol{V}_C(\boldsymbol{P}, \mathbf{O}) = v(\boldsymbol{P}, \mathbf{O}) \frac{\boldsymbol{D}(\boldsymbol{P}, \mathbf{O})}{||\boldsymbol{D}(\boldsymbol{P}, \mathbf{O})||}$$

$$v(\boldsymbol{P}, \mathbf{O}) = \frac{V_{max}}{1 + e^{||\boldsymbol{D}(\boldsymbol{P}, \mathbf{O})||(2/\rho)\alpha - \alpha}}$$



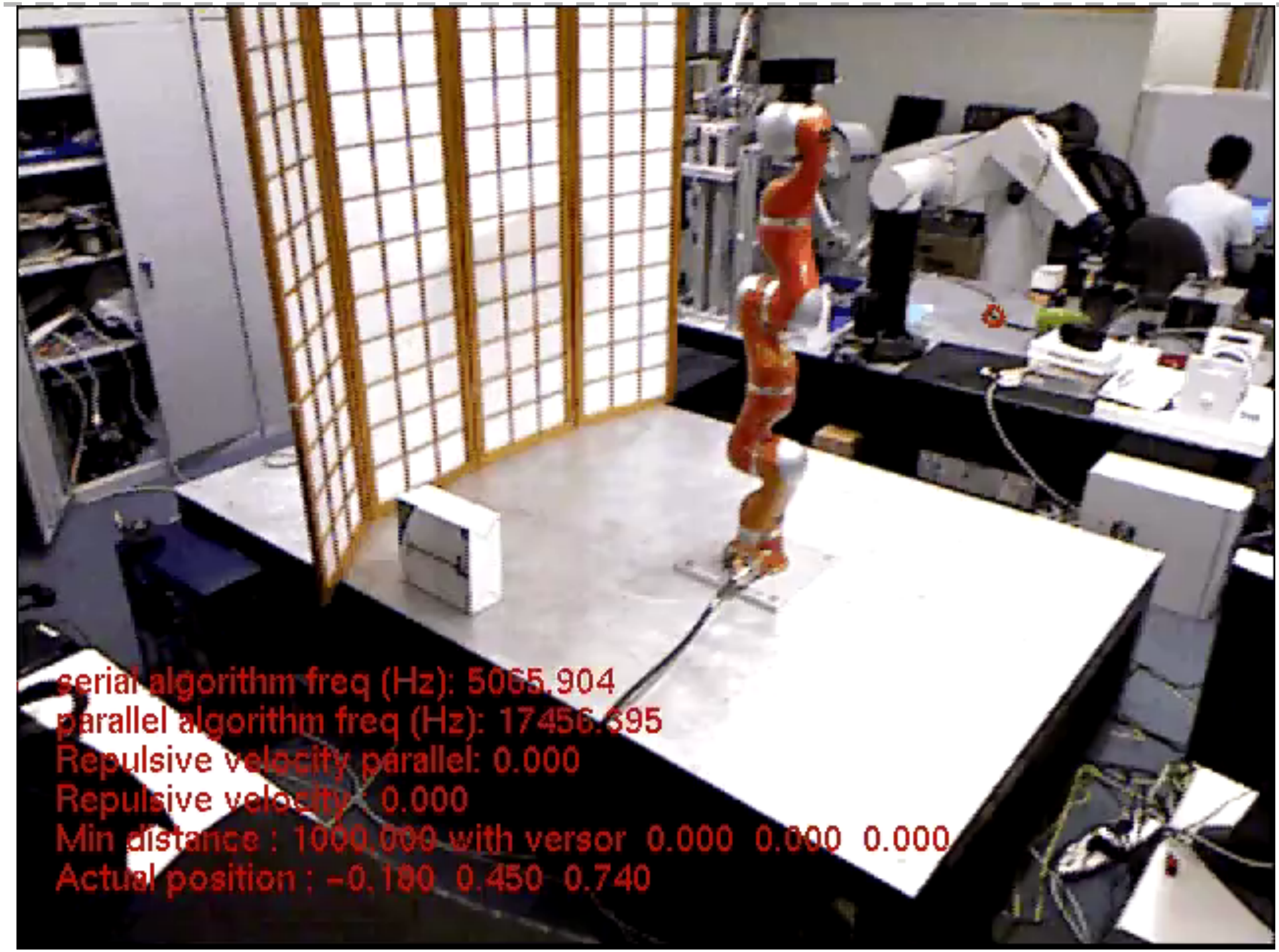
The repulsive vectors due to all obstacles near to the point of interest are considered

- orientation -> sum of all repulsive vectors
- magnitude -> nearest obstacle



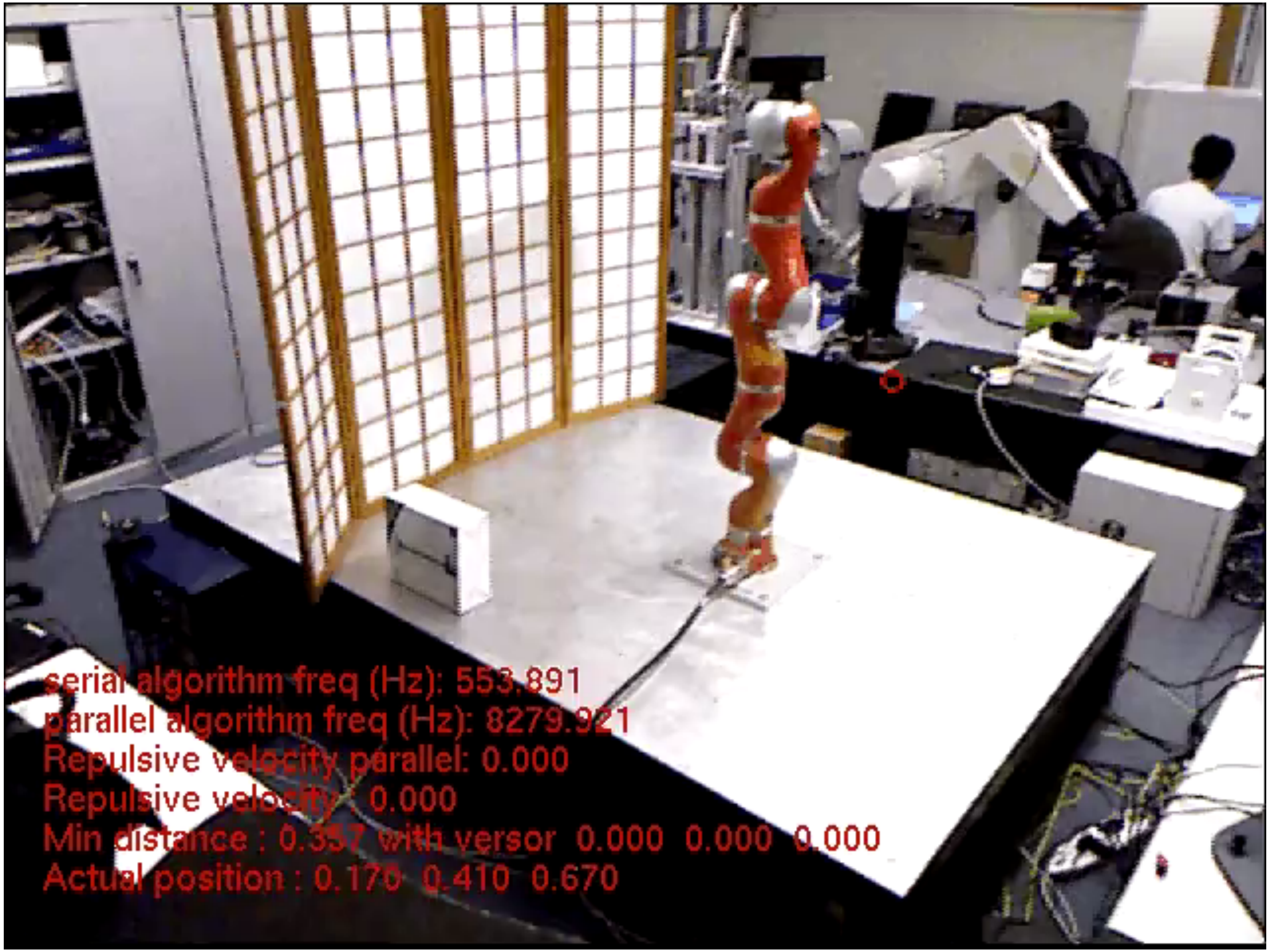
Repulsive Vector

A potential field like method



Repulsive Vector

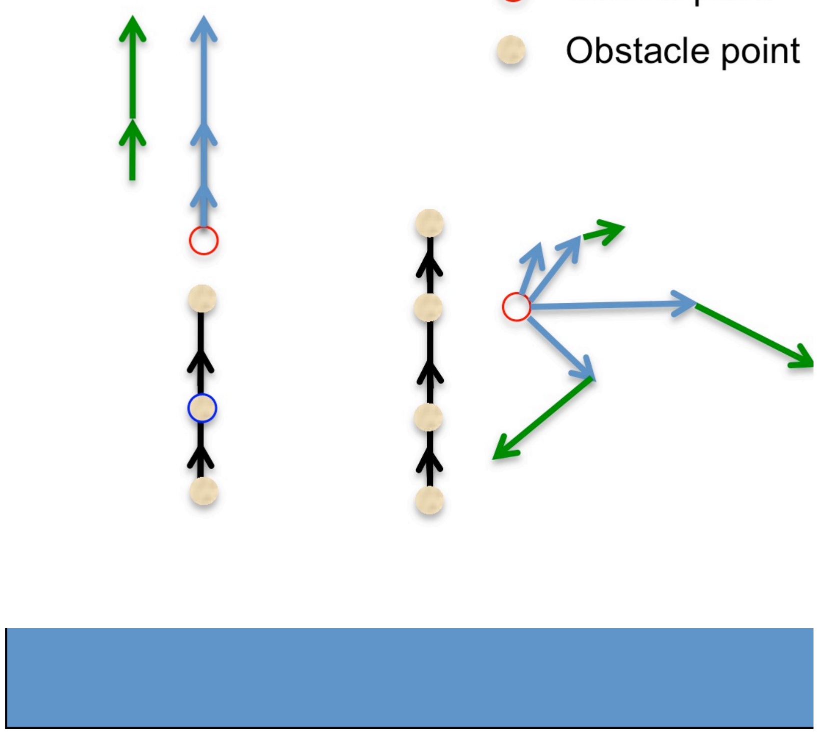
A potential field like method



Obstacle Velocity

The pivot method

Case of obstacles faster than control point



$$\boldsymbol{a} = \frac{\dot{\boldsymbol{V}}_R(\boldsymbol{P})}{\|\dot{\boldsymbol{V}}_R(\boldsymbol{P})\|}, \quad \boldsymbol{r} = \frac{\boldsymbol{V}_R(\boldsymbol{P})}{\|\boldsymbol{V}_R(\boldsymbol{P})\|}, \quad \beta = \arccos\left(\boldsymbol{a}^T \boldsymbol{r}\right)$$

if $\beta < \frac{\pi}{2}$ **then**

$$\boldsymbol{n} = \boldsymbol{a} \times \boldsymbol{r}, \quad \boldsymbol{v} = \frac{\boldsymbol{n} \times \boldsymbol{a}}{\|\boldsymbol{n} \times \boldsymbol{a}\|},$$

$$\gamma = \beta + \frac{\beta - \frac{\pi}{2}}{1 + e^{-(\|\dot{\boldsymbol{V}}_R(\boldsymbol{P})\|(2/\dot{V}_{R_{max}})-1)c}},$$

$$\boldsymbol{V}_{R_{pivot}}(\boldsymbol{P}) = \|\boldsymbol{V}_R(\boldsymbol{P})\| \left(\cos\gamma\, \boldsymbol{a} + \sin\gamma\, \boldsymbol{v}\right)$$

else

$$\boldsymbol{V}_{R_{pivot}}(\boldsymbol{P}) = \boldsymbol{V}_R(\boldsymbol{P})$$

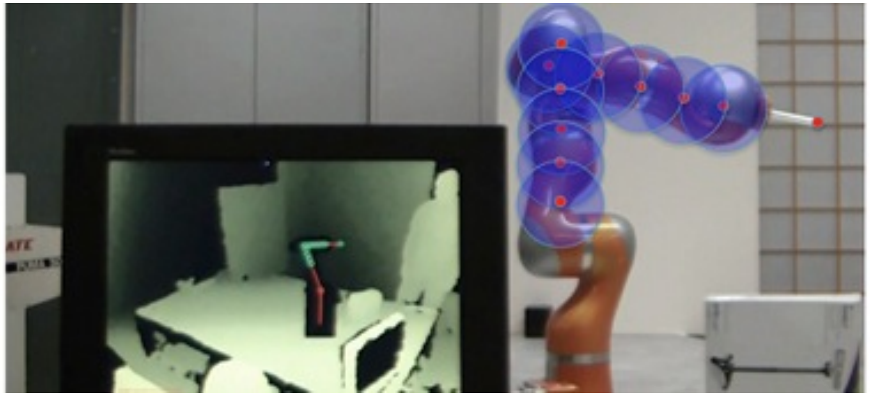
end if

Motion Control

End effector and other control points

- End effector
  repulsive vector → repulsive velocity

- Collision avoidance for the robot body



Repulsive vector

Cartesian Constrains

Joint velocity limit

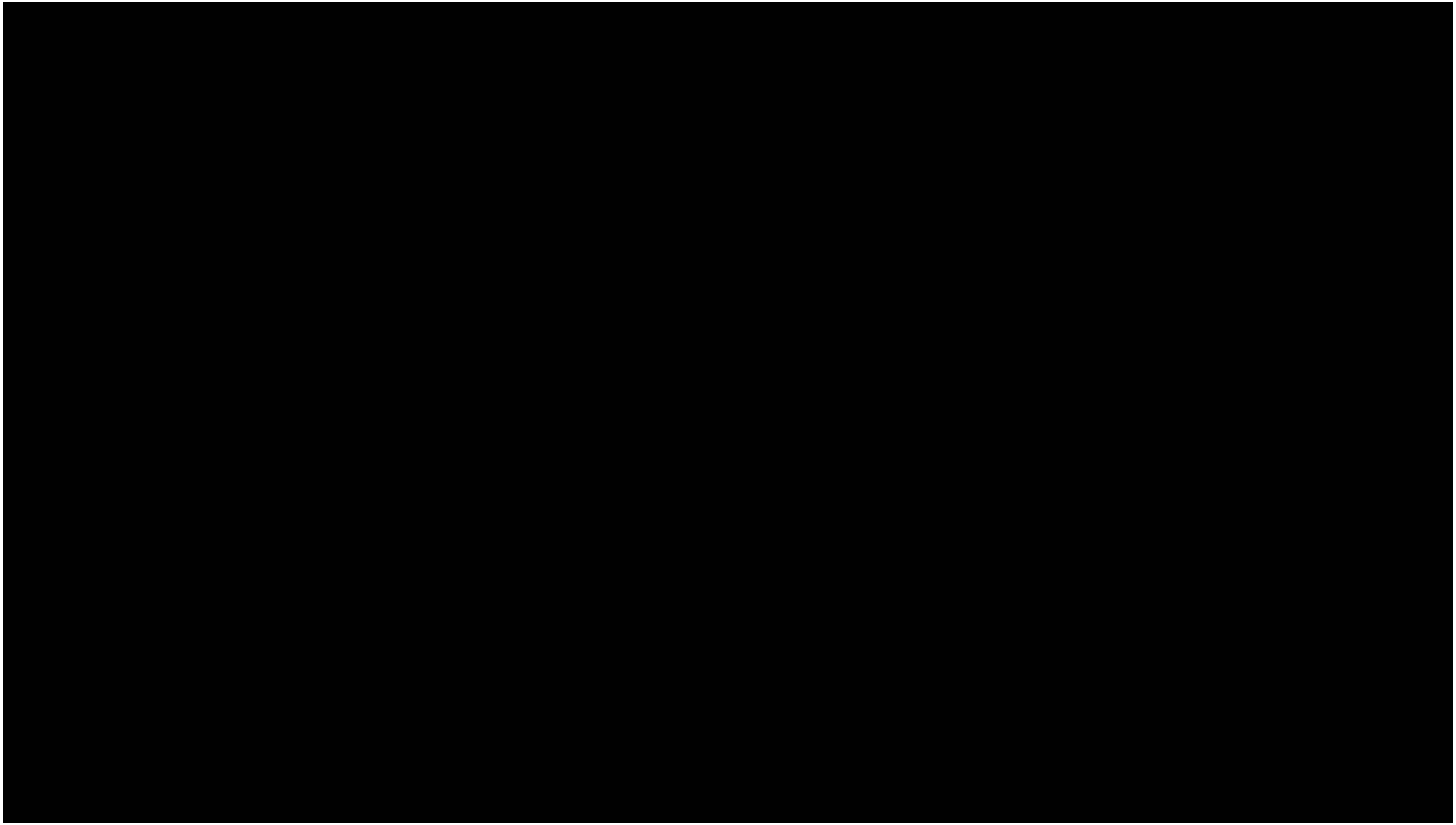
- Fluid, jerk limited motions → feeling of safety

Reflexxes GmbH

www.reflexxes.com

Safe Coexistence

Collision avoidance in depth space



Collaboration

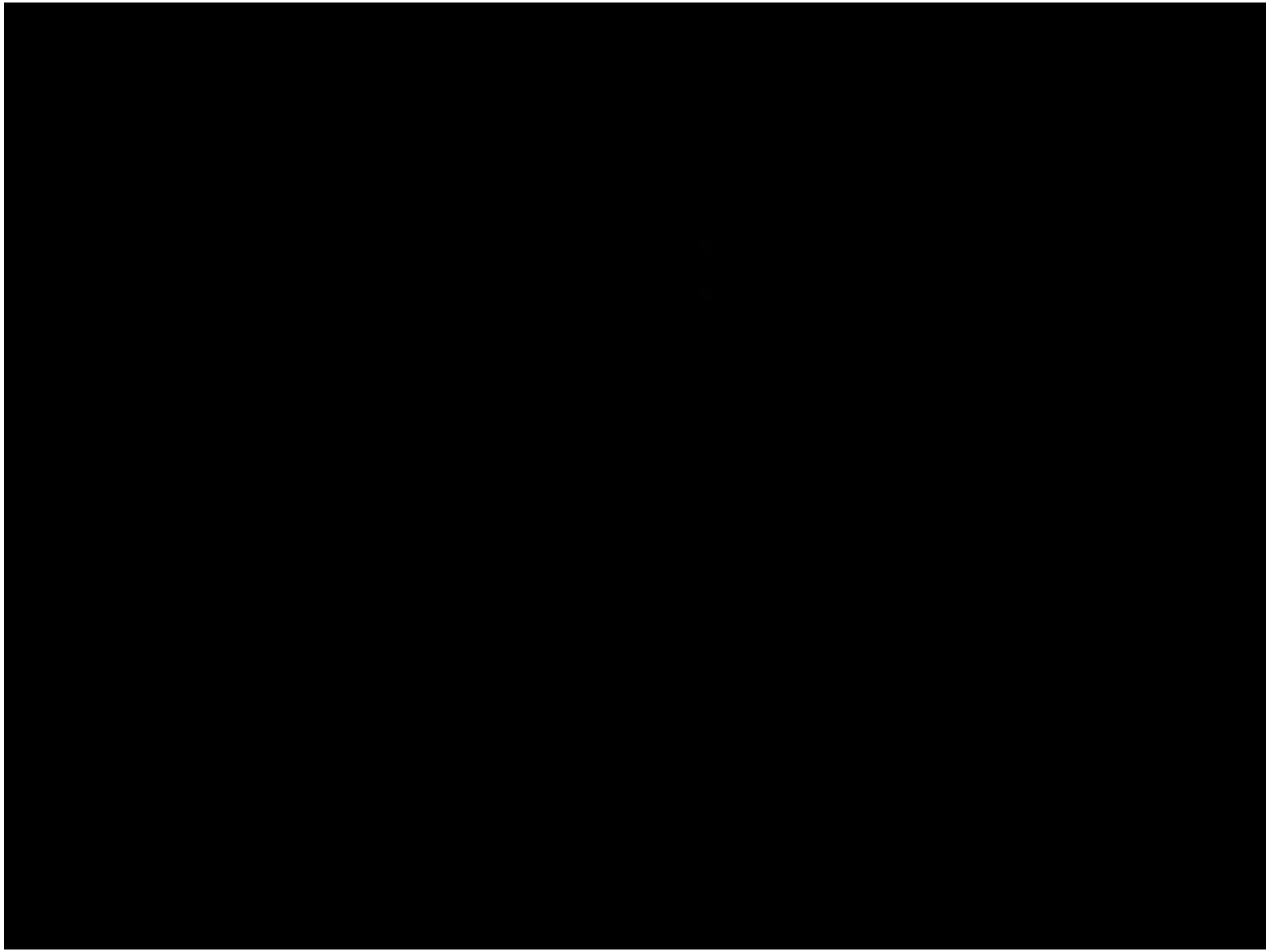
Physical and contactless

In physical collaboration, there is an explicit and intentional contact with exchange of forces between human and robot. By measuring or estimating these forces, the robot can predict human motion intentions and react accordingly.

In contactless collaboration, there is no physical interaction: coordinated actions are guided or follow from an exchange of information, which can be achieved via direct commu- nication, like with gestures and/or voice commands, or indirect communication, by recognizing intentions or attention, e.g., through eye gaze.

Safe Physical Collaboration

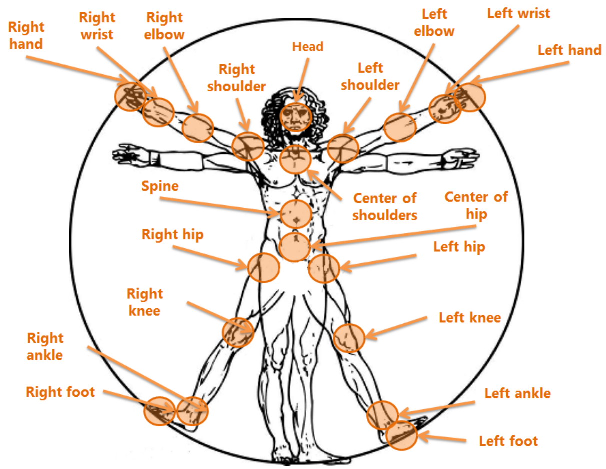
Allow contacts

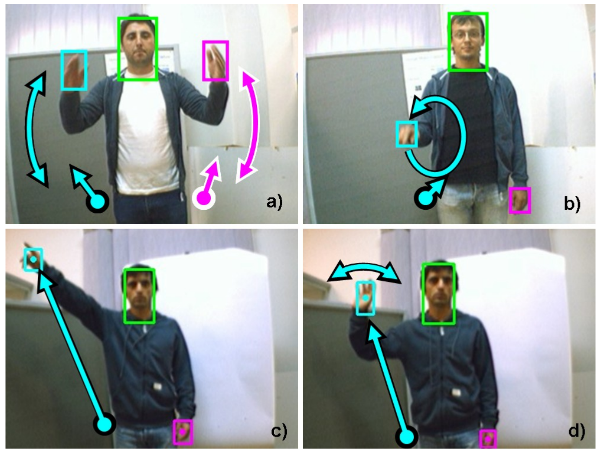


Contactless Collaboration

Voice and Gesture

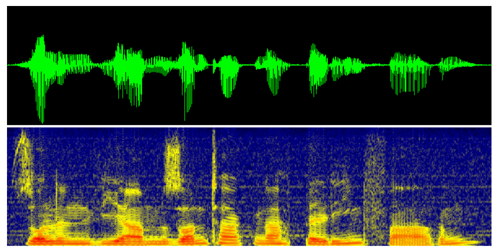
From human body to gesture recognition





Speech recognition

Start Collaboration



Starting Collaboration

Contactless Collaboration

Voice and Gesture

Contactless Collaboration

Voice and Gesture

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