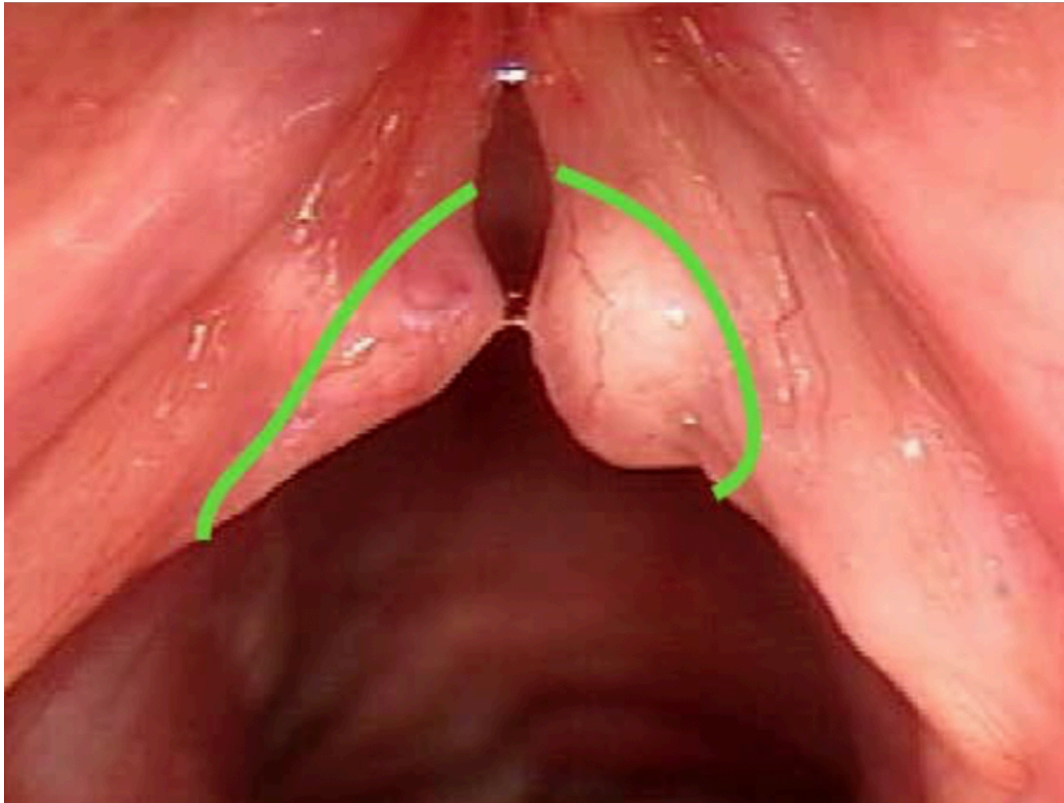
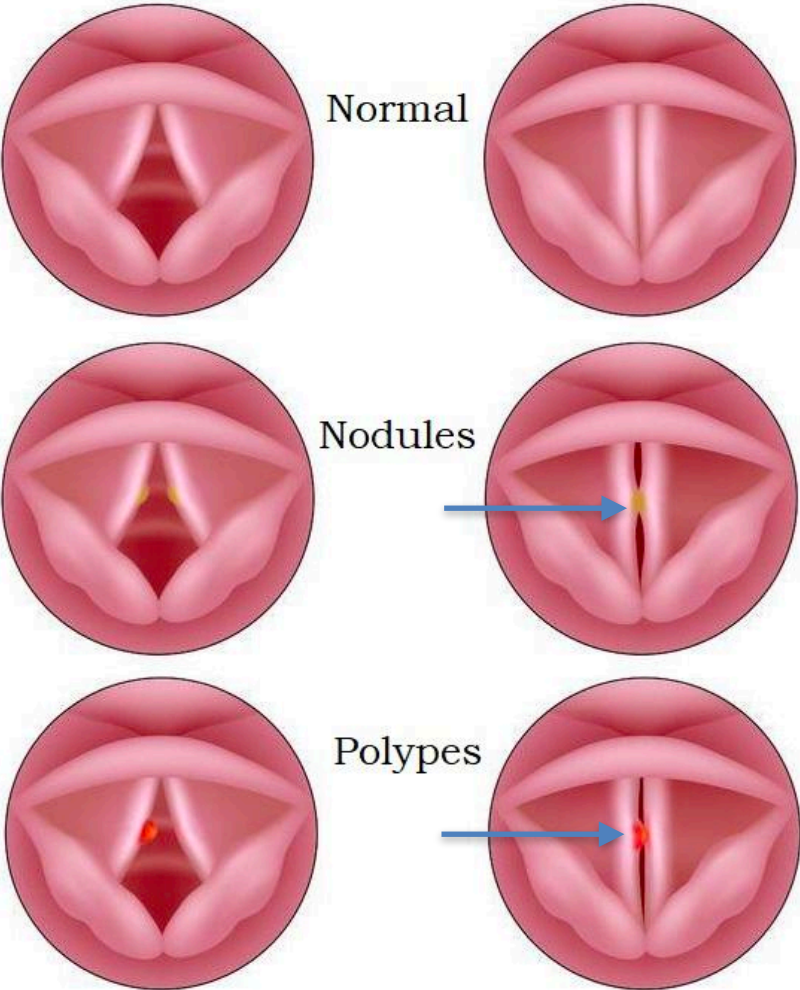




Laser surgery devices and control schemes

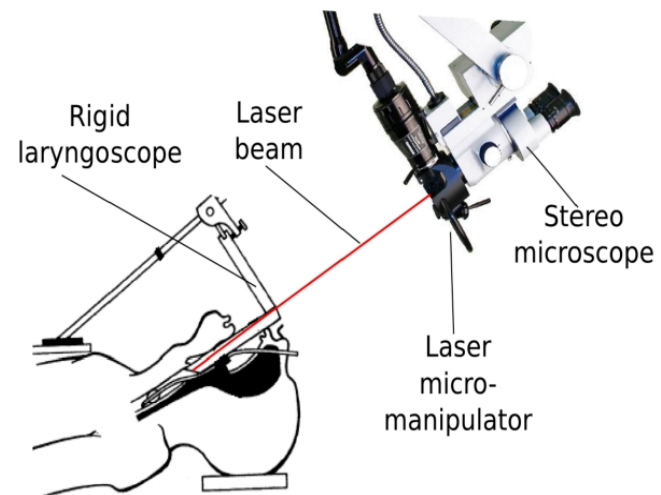
Brahim TAMADAZTE, FEMTO-ST/CNRS

Helsinki, July, 1-5th, 2019





The AcuBlade system



Designed system

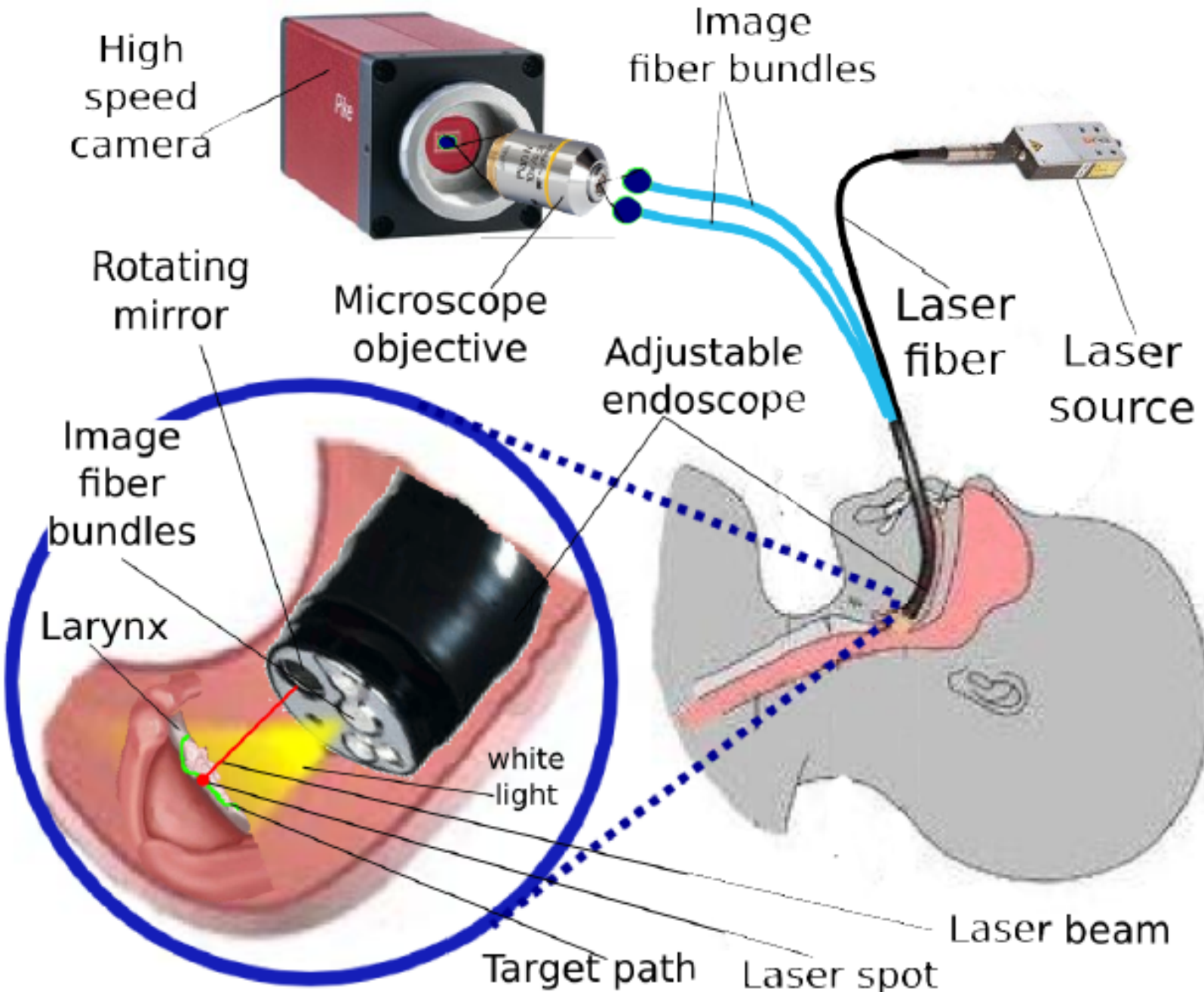


uRALP - EU-project (2012-2015)

- IIT Genova (IT),
- FEMTO-ST (FR),
- LUH Hannover (GE),
- CHRUB (FR),
- UNIGE (IT)



Designed system

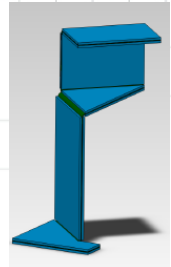
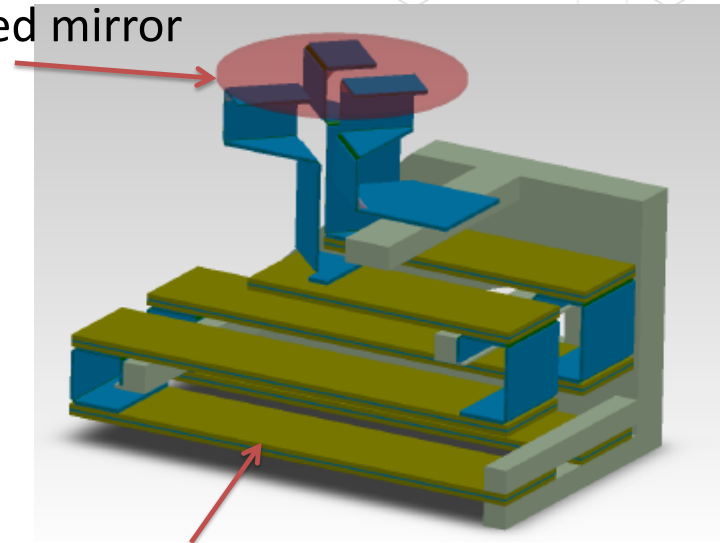


laser beam steering mirror (microrobot)

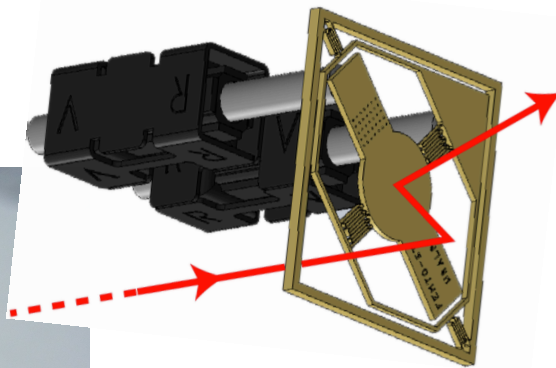
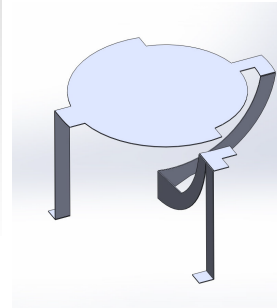
Requirements:

- High precision and repeatability
- High speed (>400 Hz)
- Low Hysteresis
- Only few millimeters of size
- High deformation range
- Ergonomic, user-friendly

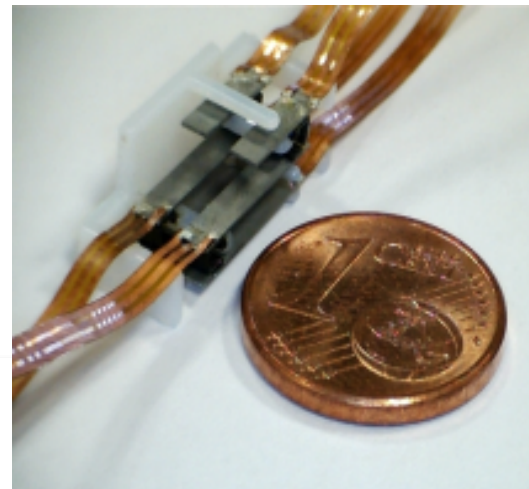
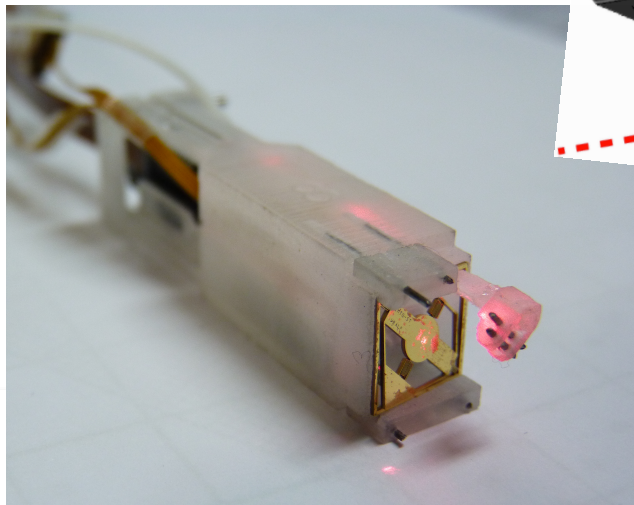
Reflected mirror



Leg



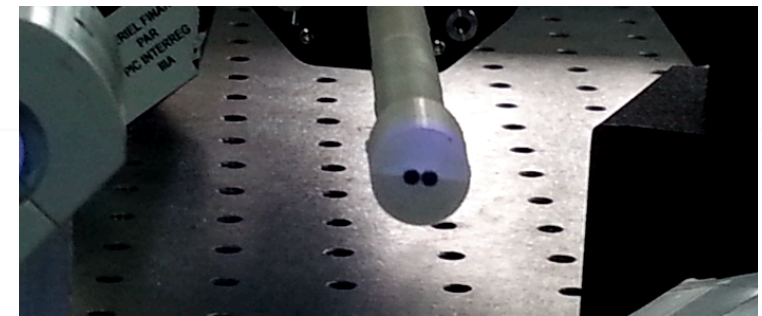
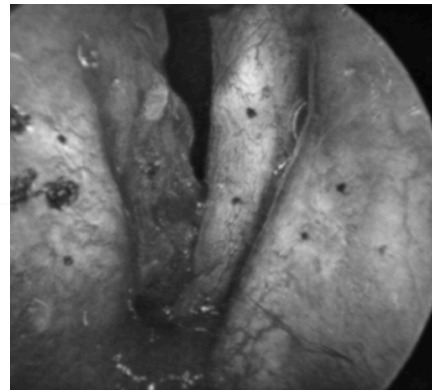
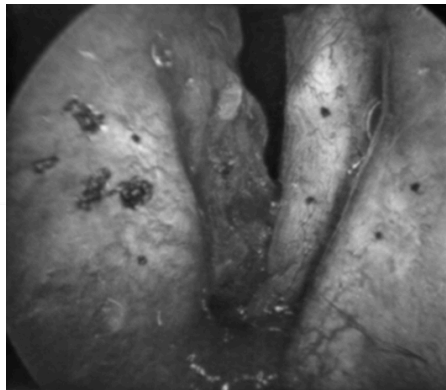
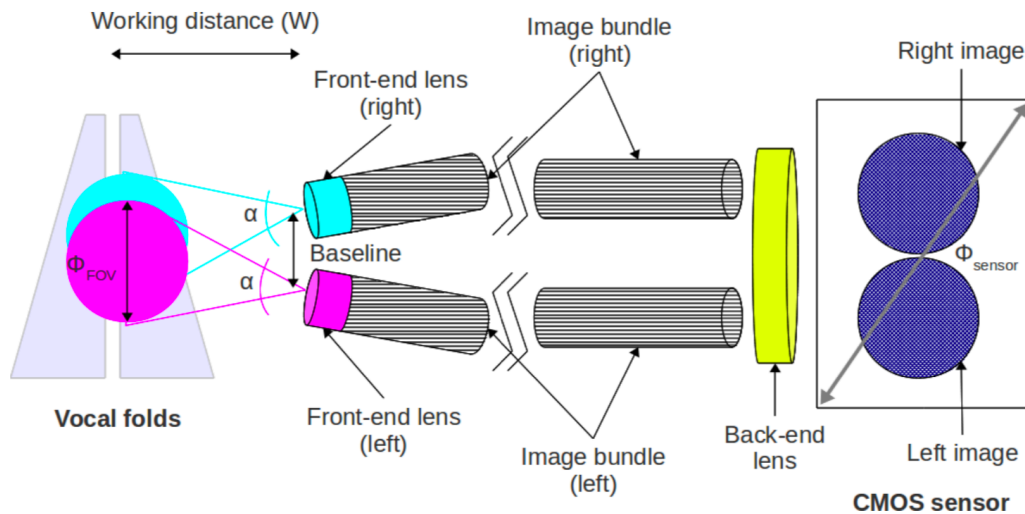
Bimorph piezo (PZT)



high-speed stereo vision system

Requirements:

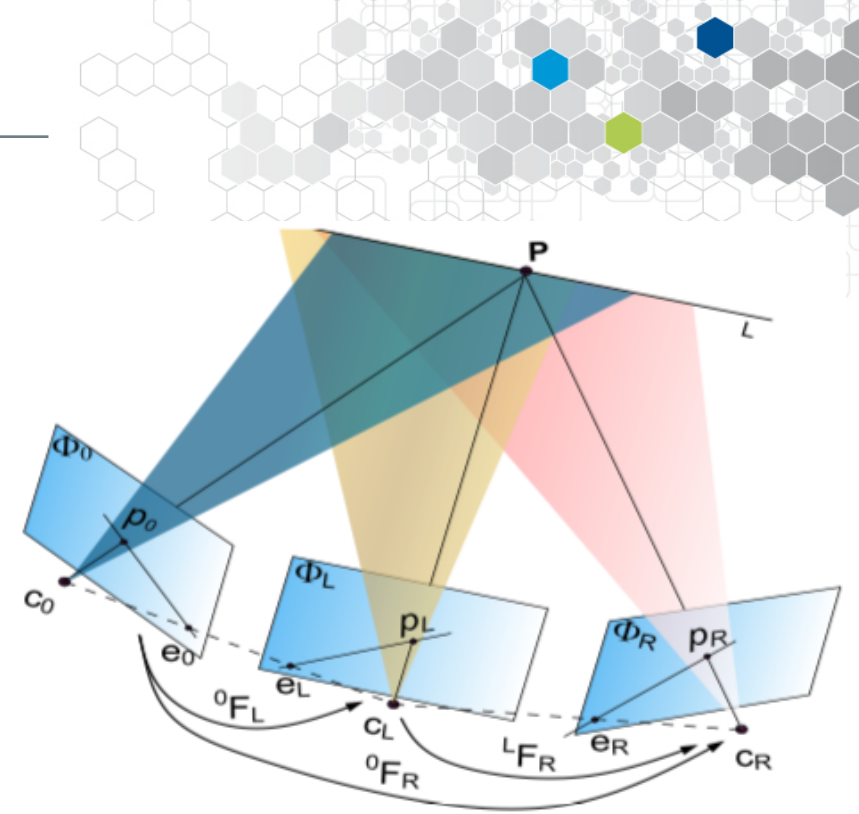
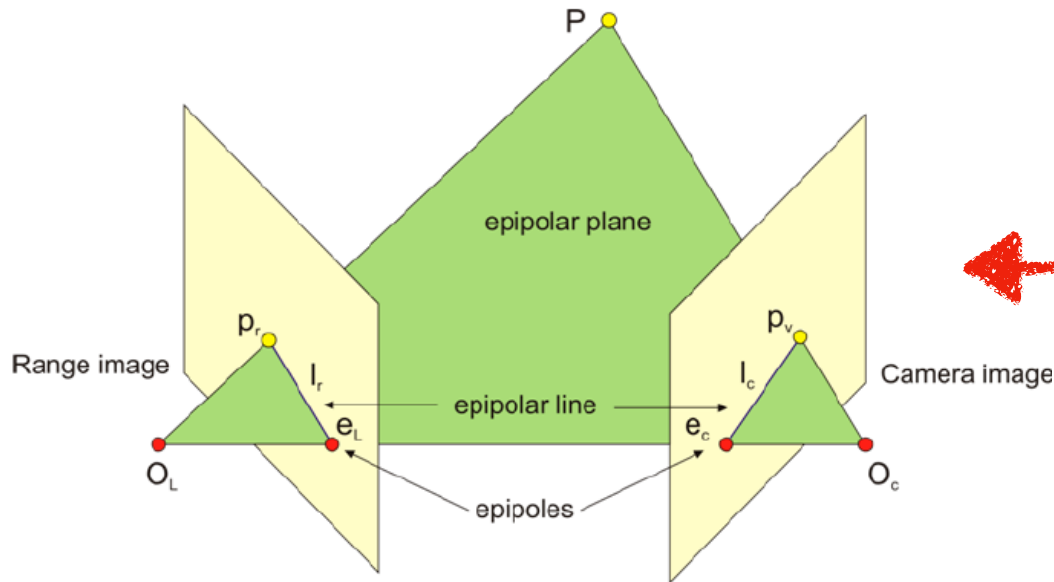
- High speed (>400 Hz)
- High sensitivity and good signal noise ratio
- 2 ou 3 millimeters of diameter



Designed system



Laser beam steering (vision-based control)



Duality between points and lines

$$\tilde{p}_L^\top {}^L F_R \tilde{p}_R = 0$$

- fundamental matrix
- epipolar points
- epipolar plane

Relationship between different image-points

$$\tilde{p}_0^\top {}^0 F_L \tilde{p}_L = 0$$

$$\tilde{p}_L^\top {}^L F_R \tilde{p}_R = 0$$

$$\tilde{p}_0^\top {}^0 F_R \tilde{p}_R^\top = 0$$

Traditional trifocal constraint

$$[\tilde{p}_L]_\times \left(\sum_{i=1}^3 \tilde{p}_i \mathbf{T}_i \right) [\tilde{p}_R]_\times = 0_{3 \times 3}$$

(Hartley & Zisserman, 2003)

Laser beam steering (vision-based control)

- The laser beam direction ${}^0\mathbf{z}$ is geometrically equivalent to the point $\tilde{\mathbf{p}}_0$

$${}^0\mathbf{z} \equiv \tilde{\mathbf{p}}_0$$

$$\tilde{\mathbf{p}}_0^T {}^0\mathbf{F}_L \tilde{\mathbf{p}}_L = 0$$

$$\tilde{\mathbf{p}}_L^T {}^L\mathbf{F}_R \tilde{\mathbf{p}}_R = 0$$

$$\tilde{\mathbf{p}}_L^T {}^L\mathbf{F}_R \tilde{\mathbf{p}}_R = 0$$



$${}^0\mathbf{z}^T {}^0\mathbf{F}_R \tilde{\mathbf{p}}_R = 0$$

$$\tilde{\mathbf{p}}_0^T {}^0\mathbf{F}_R \tilde{\mathbf{p}}_R = 0$$

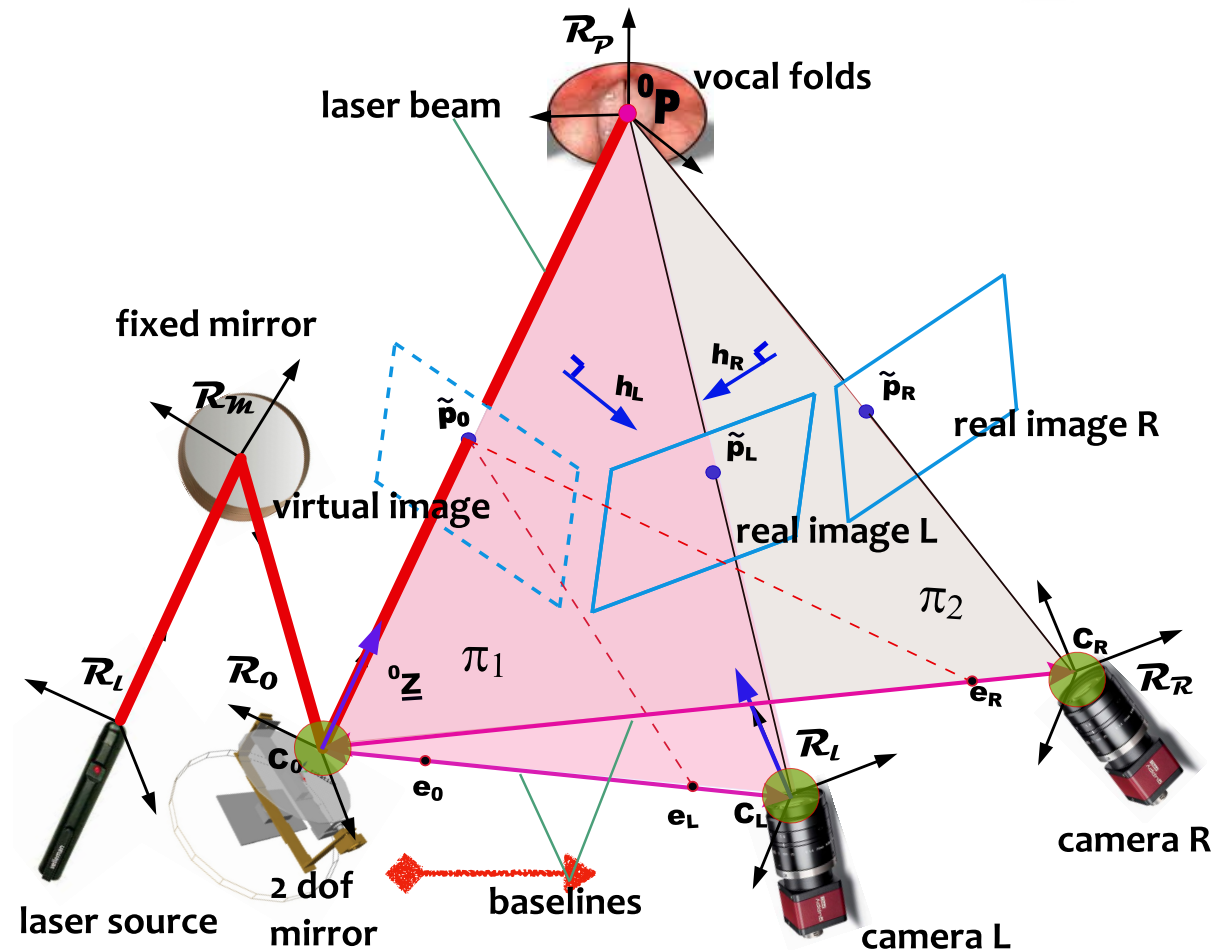
$${}^0\mathbf{z}^T {}^0\mathbf{F}_L \tilde{\mathbf{p}}_L = 0$$

$${}^0\mathbf{z} \times (\mathbf{h}_R \times \mathbf{h}_L) = 0$$



$$\begin{cases} \mathbf{h}_L = {}^0\mathbf{F}_L \tilde{\mathbf{p}}_L \\ \mathbf{h}_R = {}^0\mathbf{F}_R \tilde{\mathbf{p}}_R \end{cases}$$

$${}^0\mathbf{z} \times ({}^0\mathbf{F}_R \tilde{\mathbf{p}}_R \times {}^0\mathbf{F}_L \tilde{\mathbf{p}}_L) = 0$$



Control law:

$$\omega = \lambda \frac{\mathbf{h}_R \times \mathbf{h}_L}{\|\mathbf{h}_R \times \mathbf{h}_L\|^2} \times \left(\mathbf{h}_L \times ({}^0\mathbf{F}_R (\tilde{\mathbf{p}}_r - \tilde{\mathbf{p}}_R^*)) - \mathbf{h}_R \times ({}^0\mathbf{F}_L (\tilde{\mathbf{p}}_l - \tilde{\mathbf{p}}_L^*)) \right)$$



- No precise calibration (e.g., mirror/camera)
- High accuracy (<50 micrometers)
- High frequency
- Easy to implement (20 lines of code (C++))
- Implicit depth estimation

Laser Steering using Virtual Trifocal Visual Servoing

N. Andreff and B. Tamadazte
FEMTO-ST Institute, 25000, Besançon, France

“Validation on a 2D target”

Multimedia Extension #2

International Journal of Robotics Research

Laser Steering using Virtual Trifocal Visual Servoing

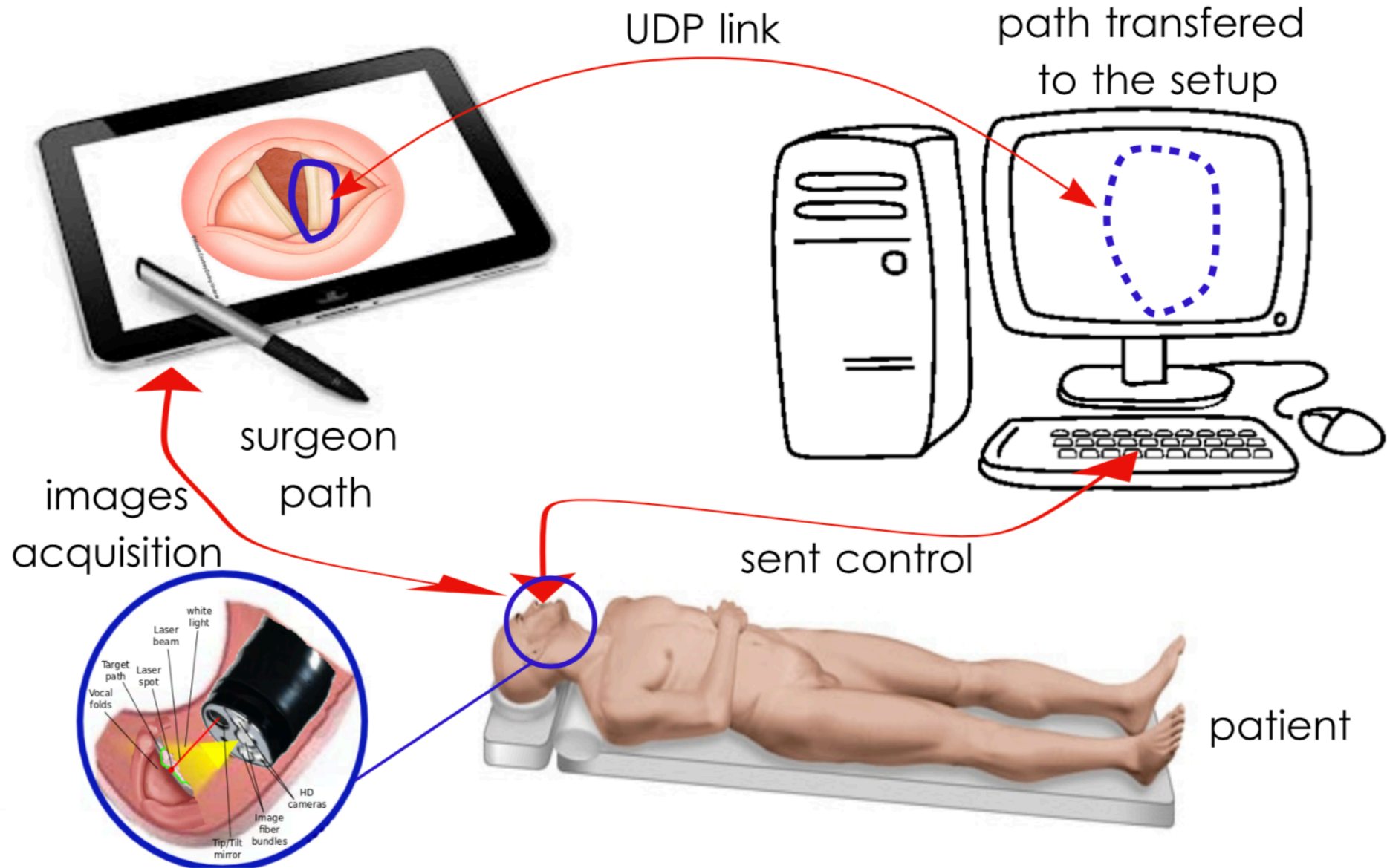
N. Andreff and B. Tamadazte
FEMTO-ST Institute, 25000, Besançon, France

“Validation on a 3D target”

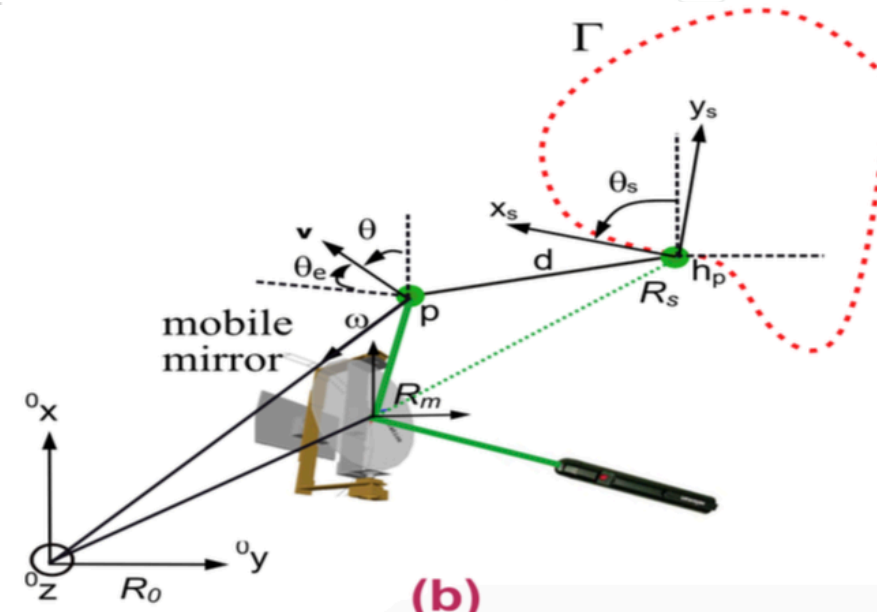
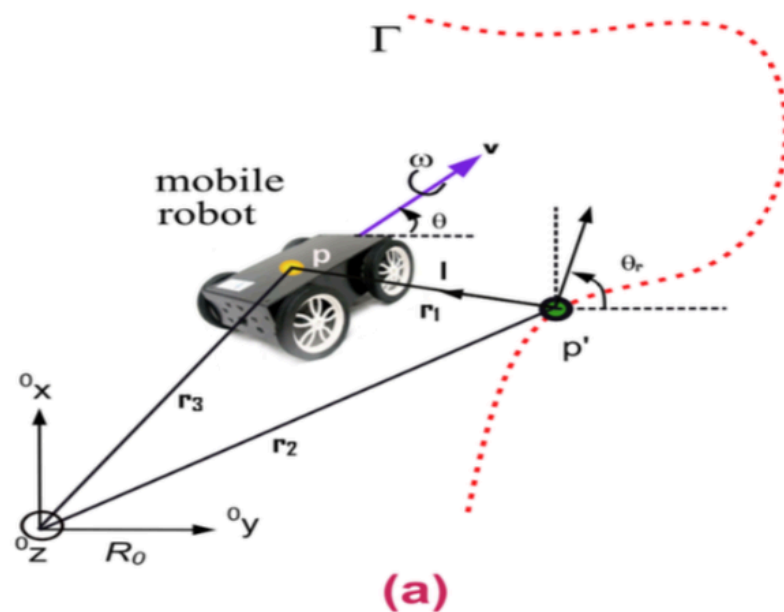
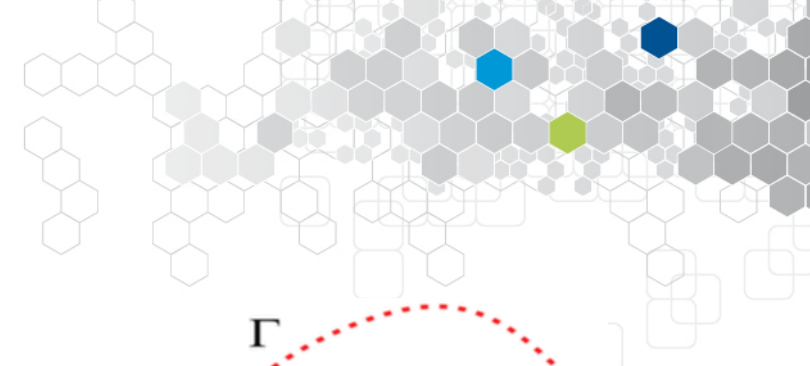
Multimedia Extension #3

International Journal of Robotics Research

Laser beam steering (vision-based control)



Laser beam steering (vision-based control)



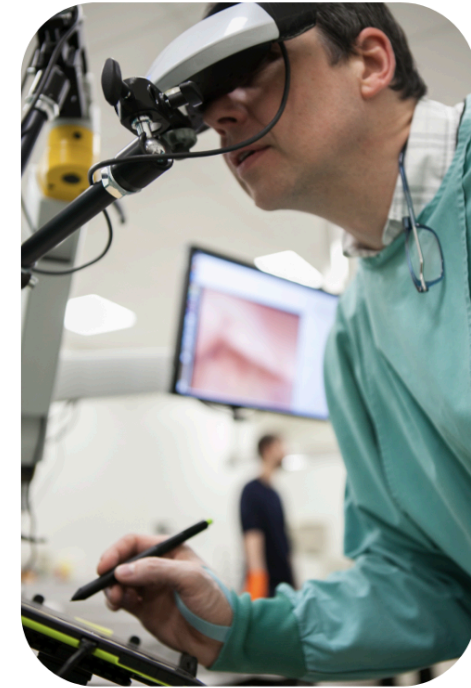
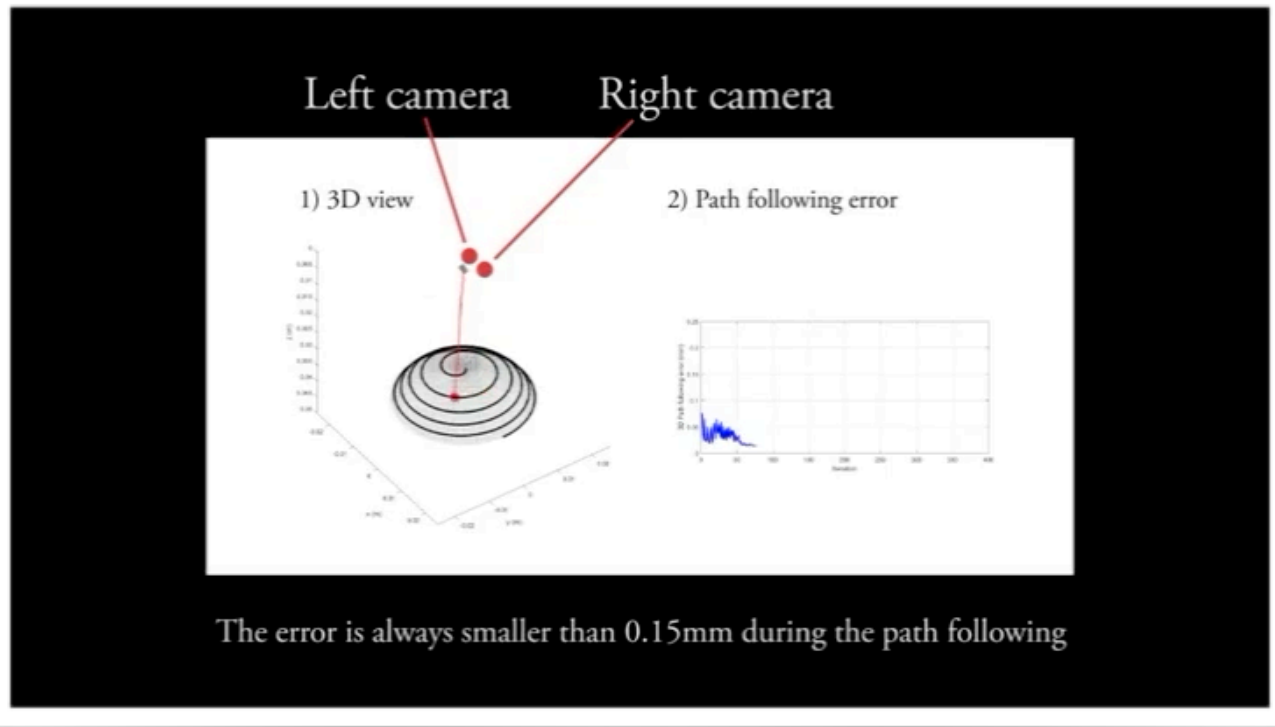
(Morin & Samson, 2006)

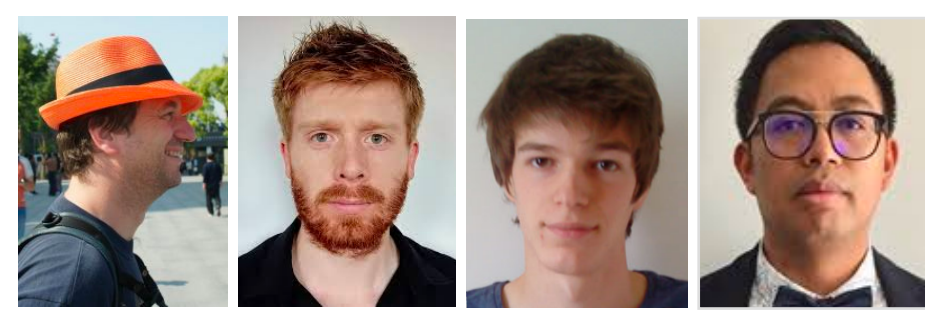
$$\begin{aligned} \dot{x} &= v \cos \theta \\ \dot{y} &= v \sin \theta \\ \dot{\theta} &= \omega \end{aligned}$$

$$\omega = \frac{u_2 + \left(\dot{C}(s) + d \frac{\partial C(s)}{\partial s} \dot{s} \right) \tan \theta_e}{(1 - dC(s))(1 + \tan^2 \theta_e)} + \dot{s}C(s)$$

$$\mathbf{v}_{k+1} = \frac{\mathbf{v}_k + \omega^0 \mathbf{z} \times \mathbf{v}_k}{\|\mathbf{v}_k + \omega^0 \mathbf{z} \times \mathbf{v}_k\|}$$

Laser beam steering (vision-based control)





Besançon



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