Dynamical System-based Imitation Learning for Visual Servoing using the Large Projection Formulation

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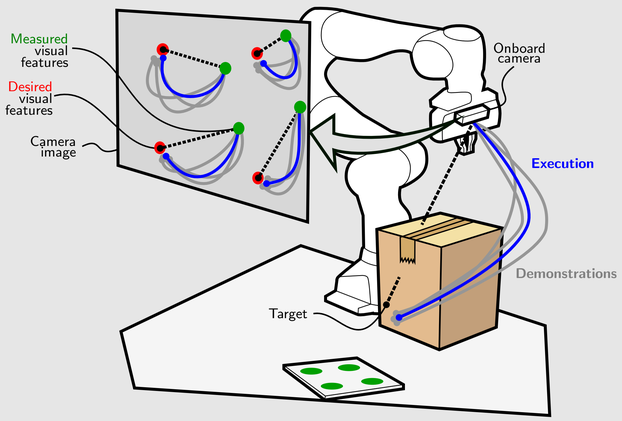
Imitation Learning for Visual Servoing (ILVS)



Proposed solution

- *Imitation Learning* for *Visual Servoing (ILVS)* inspired by *Dynamical Systems*
- The *large projector* is used to *keep the stability* while *imitating complex motion*
- The approach allows to easily generate *complex and adaptive* motion
- The visual feedback adds *adaptability* to the imitation learning
- The ILVS strategy adds tasks or constraints to VS *without explicit coding*

ILVS using the large projector

- *Standard VS* zeroes the error $\boldsymbol{e}$ between measured and desired features

$$\boldsymbol{v} = -\lambda \boldsymbol{L}^{+} \boldsymbol{e}$$

where $\boldsymbol{v}$ is the camera velocity, λ the gain and $\boldsymbol{L}$ the image Jacobian

- A *secondary task* can be added using the *projector operator* $\boldsymbol{P} = \boldsymbol{I} - \boldsymbol{L}^{+}\boldsymbol{L}$

$$\boldsymbol{v} = -\lambda \boldsymbol{L}^{+} \boldsymbol{e} + \boldsymbol{P}\boldsymbol{\sigma}$$

where $\boldsymbol{\sigma}$ is camera velocity realizing the secondary task

- To enable more space for the secondary task one can use the *error norm*

$$\boldsymbol{v} = -\lambda \eta \boldsymbol{L}_{\eta}^{+} + \boldsymbol{P}_{\eta}\boldsymbol{\sigma}, \quad \eta = \|\boldsymbol{e}\|$$

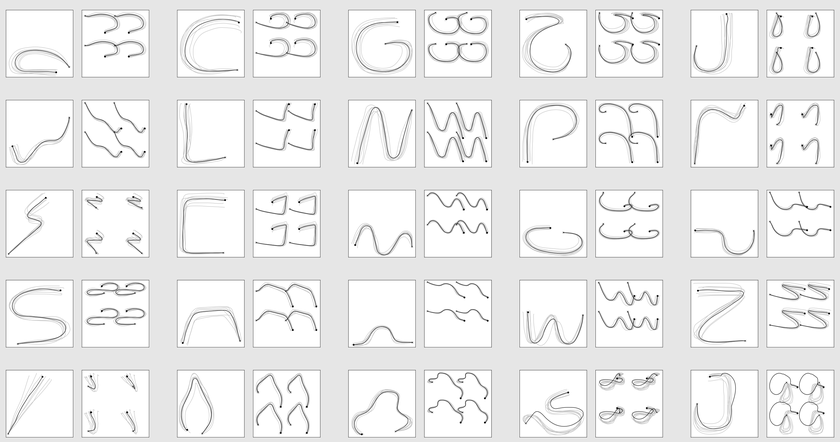
- This control structure is used to *imitate complex motion* and *keep stability*

Error norm tracking with velocity imitation

- Very *complex trajectories* follow non-exponential, non-monotonic decay of η
- We propose to imitate *demonstrated velocities* as a secondary task and track a *desired norm taken from data*

$$\boldsymbol{v} = \underbrace{\left(\dot{\eta}_d - \lambda(\eta - \eta_d)\right)\boldsymbol{L}_{\eta}^{+}\boldsymbol{e}}_{\text{stable error norm tracking}} + \underbrace{\boldsymbol{P}_{\eta}\boldsymbol{\sigma}}_{\text{velocity imitation}}$$

Simulation analysis on the LASA dataset



Learning VS tasks

- We consider data from D visual task demonstrations of N samples:

$$\mathcal{D} = \left\{\boldsymbol{e}_n^d,\ \boldsymbol{v}_n^d\right\}_{n=1,d=1}^{N,D}, \quad \mathcal{H} = \left\{\tau_n^d,\ \dot{\eta}_n^d\right\}_{n=1,d=1}^{N,D}$$

where τ_n^d in a time-like variable linearly increasing from 0 to 1

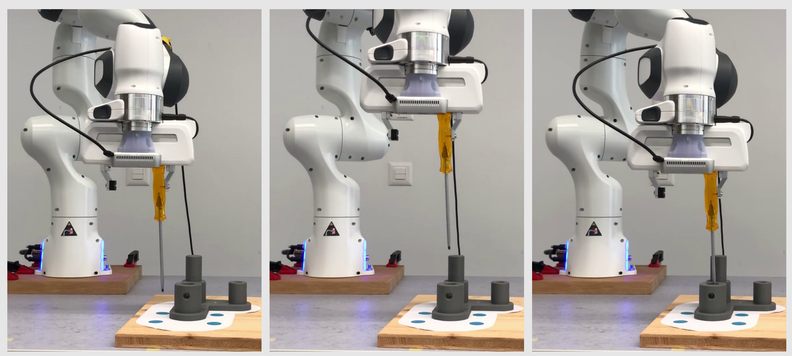
- The velocity to imitate is inferred from $\mathcal{D}$ using the current value of $\boldsymbol{e}$

$$\boldsymbol{\sigma} = \boldsymbol{r}_{\sigma}\left(\boldsymbol{e} \,|\, \mathcal{D}\right)$$

- Time derivative of η_d is taken from $\mathcal{H}$ using a time-like variable τ

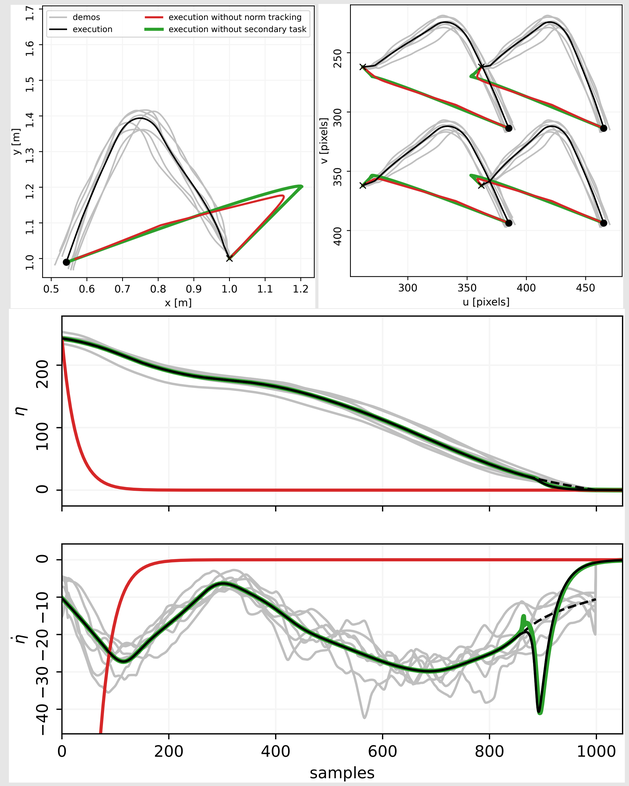
$$\dot{\eta}_d = \boldsymbol{r}_{\eta}\left(\tau \,|\, \mathcal{H}\right)$$

Robot experiment



- In complex tasks, IL allows easy robot programming, and VS allows to adapt the learned motion to changes in the environment

Simulation



- Comparison with the different components of the controller