Agimus Winter School
11/12/2023 - 15/12/2023
Banyuls (France)

AGIMUS
INNOVATIVE ROBOTICS FOR AGILE PRODUCTION

Model-based object pose tracking

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Founded by the European Union under GA no 101070165

Object pose tracking

Initial pose

Converged

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Initial pose

Converged

- Assumptions: object detected, matched with model, initial pose

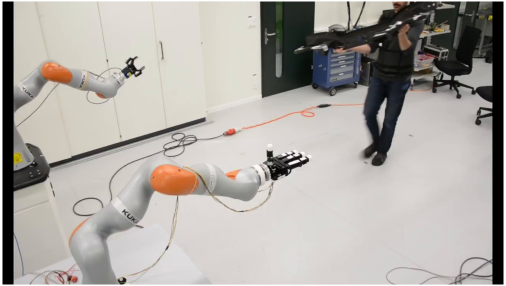
Object pose tracking

Initial pose

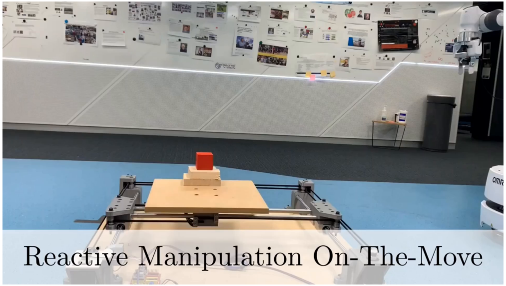
Converged

- Assumptions: object detected, matched with model, initial pose
- Local refinement of ${}^{c}\mathrm{T}_b \in SE(3)$ pose using a single RGB(-D) camera

Motivation: dynamic manipulation

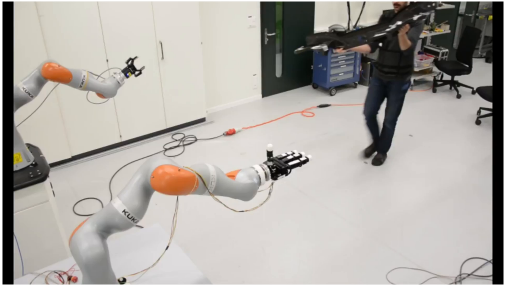


Human to robot handover [MFB18]



Object grasping on the move [Bur+23]

Motivation: dynamic manipulation



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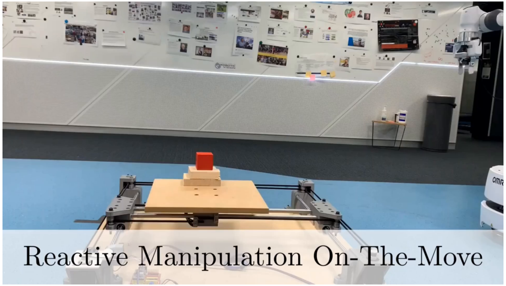
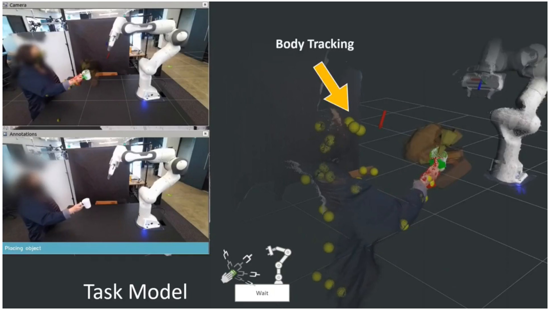


Object grasping on the move [Bur+23]

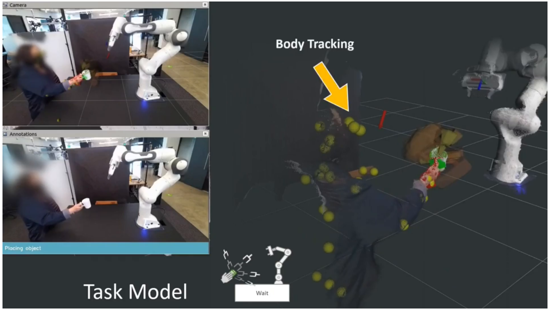
- Low latency estimation to close the loop
- Grasping level precision ($\sim$ cm)

Handover from point cloud grasp prediction



Model predictive control for fluid human-to-robot handovers [Yan+22]

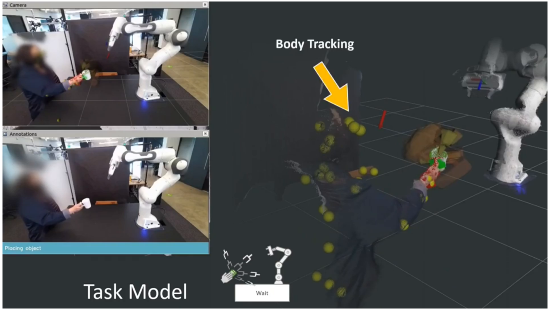
Handover from point cloud grasp prediction



Model predictive control for fluid human-to-robot handovers [Yan+22]

- Generates grasp proposals from point cloud (GraspNet)

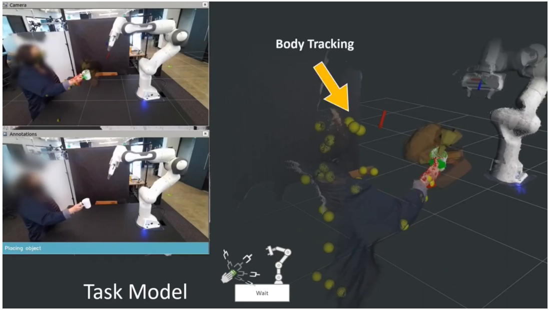
Handover from point cloud grasp prediction



Model predictive control for fluid human-to-robot handovers [Yan+22]

- Generates grasp proposals from point cloud (GraspNet)
- Runs on 6 GPUs in parallel

Handover from point cloud grasp prediction



Model predictive control for fluid human-to-robot handovers [Yan+22]

- Generates grasp proposals from point cloud (GraspNet)
- Runs on 6 GPUs in parallel
- What if we have a decent object model?

Overview

1. Model based object tracking, a short tour
2. Region based object tracking
3. Object localization and tracking for conrol

Model based object tracking

A short tour

Edges tracking

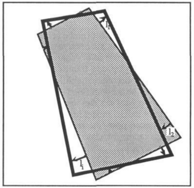


Figure 2: Diagram to show a sample of perpendicular distances, l_i

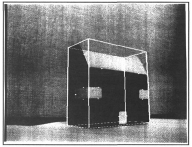
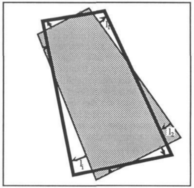


Figure 4: RAPID tracking box in a static situation

RAPID [HS90]

- **Model**: 3D geometric primitives
- **Method**: Local search for image edges from contour points, least squares

Edges tracking



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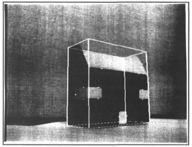
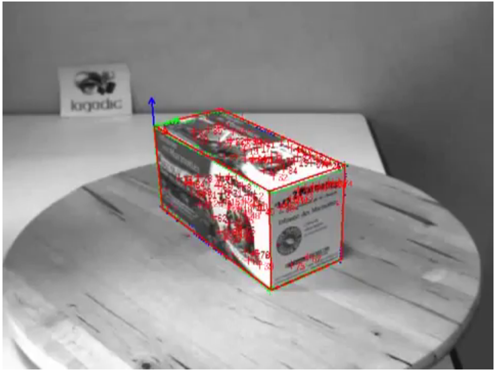


Figure 4: RAPID tracking box in a static situation

RAPID [HS90]

- **Model**: 3D geometric primitives
- **Method**: Local search for image edges from contour points, least squares
- First real time methods
- Sensitive to incorrect matches (background clutter, self occlusion), additional modelling step

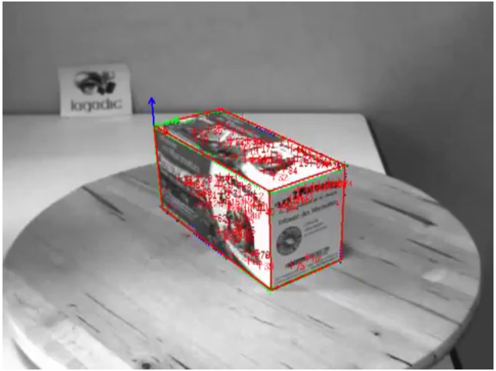
Keypoint matching



Hybrid tracking, ViSP [Com+06]

- **Model**: 3D point with descriptors
- **Method**: 3D-2D matching, minimize reprojection error (PnP problem)

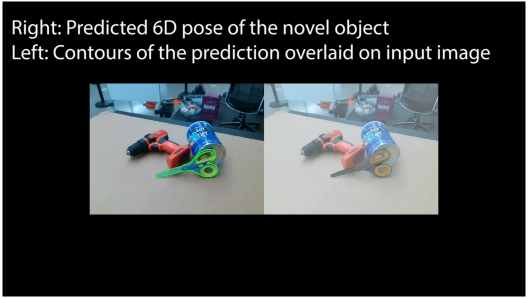
Keypoint matching



Hybrid tracking, ViSP [Com+06]

- **Model**: 3D point with descriptors
- **Method**: 3D-2D matching, minimize reprojection error (PnP problem)
- Efficient and robust if rich texture
- Fails for object with low texture

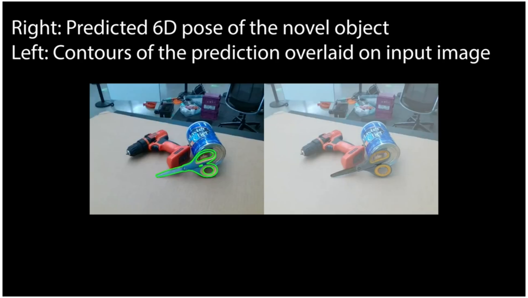
Deep learning



Megapose, tracking mode (2022) [Lab+22]
Also: PoseRBPF [Den+21],
se(3)-TrackNet [Wen+20]...

- **Model**: textured mesh
- **Method**: render and compare, regress delta pose

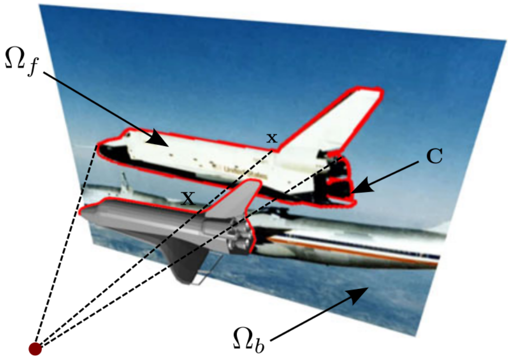
Deep learning



Megapose, tracking mode (2022) [Lab+22]
Also: PoseRBPF [Den+21],
se(3)-TrackNet [Wen+20]...

- **Model**: textured mesh
- **Method**: render and compare, regress delta pose
- Robust to occlusions, clutter, etc. Sota on standard benchmarks
- High-end GPUs at run-time, costly training, generalization ($\sim$)

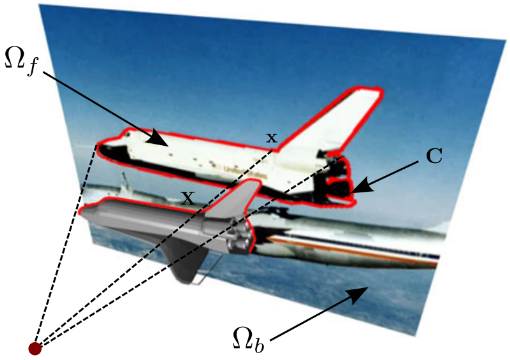
Region based tracking



PWP3D [PR12]

- **Model**: mesh (no texture)
- **Method**: probabilistic silhouette alignment, Newton's method

Region based tracking



PWP3D [PR12]

- **Model**: mesh (no texture)
- **Method**: probabilistic silhouette alignment, Newton's method
- Robust to occlusions, clutter, very efficient (1 object $\rightarrow$ $\sim$1000 FPS on CPU)
- Assumes foreground and background colors sufficiently different

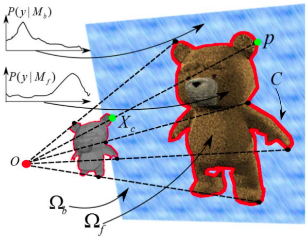
Region based tracking

SRT3D, sparse region based tracking [Sto+22]

Dense region based tracking for pose tracking

Objective: find ${}^{c}\mathrm{T}_b$ that maximizes likelihood of segmentation

$$P({}^{c}\mathrm{T}_b|\mathrm{Img}) = \prod_{x\in\Omega} \left(h_b(\phi)\cdot P_b + h_f(\phi)\cdot P_f\right)$$



Foreground/background probability distributions [Zha+14]

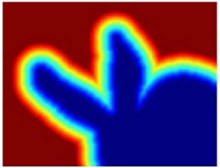
Signed Distance Function (SDF)

Objective: find ${}^{c}\mathrm{T}_b$ that maximizes likelihood of segmentation

$$P({}^{c}\mathrm{T}_b|\mathrm{Img}) = \prod_{x\in\Omega}(h_b(\phi)\cdot P_b + h_f(\phi)\cdot P_f)$$

- $\phi = f({}^{c}\mathrm{T}_b)$: SDF, from rendered contour

Contour from ${}^{c}\mathrm{T}_b$



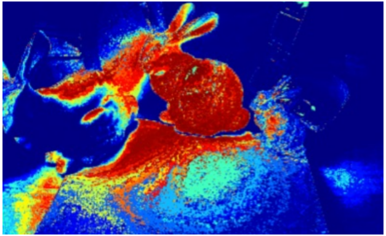
SDF

Color statistics and activation

Objective: find ${}^{c}\mathrm{T}_b$ that maximizes likelihood of segmentation

$$P({}^{c}\mathrm{T}_b|\mathrm{Img}) = \prod_{x\in\Omega}(h_b(\phi)\cdot P_b + h_f(\phi)\cdot P_f)$$

- P_b, P_f: background/foreground color distributions
- h_b, h_f: background/foreground activation functions



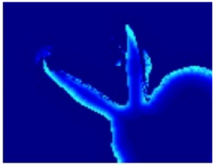
Example of P_f visualization [Keh+17]

ExecuteTrackingStep

$^{c}\mathrm{T}_b = {}^{c}\mathrm{T}_b^0$
$P_b, P_f = P_b^0, P_f^0$
for $i = 1$ to N_update_stats **do**
  for $j = 1$ to N_newton **do**
    $\mathrm{cost}({}^{c}\mathrm{T}_b) = -\log P({}^{c}\mathrm{T}_b | \mathrm{Img})$
    $\mathrm{g}, \mathrm{H} = \mathrm{ComputeCostGradientHessian}({}^{c}\mathrm{T}_b, P_b, P_f)$
    $\nu_b = \text{-}(\mathrm{H} + \lambda_{tikho} \mathrm{I}_6)^{-1} \cdot \mathrm{g}$
    $^{c}\mathrm{T}_b = \mathrm{UpdatePose}({}^{c}\mathrm{T}_b, \nu_b)$
  end for
  $P_b, P_f = \mathrm{UpdateColorStatistics}({}^{c}\mathrm{T}_b)$
end for

Are dense computations necessary?

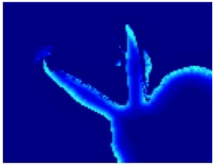
Contour prediction



Residuals $-\log P({}^{c}\mathrm{T}_{b}|\mathrm{Img})$

Are dense computations necessary?

Contour prediction



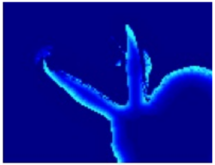
Residuals $-\log P({}^{c}\mathrm{T}_{b}|\mathrm{Img})$

Observations:

- Important residuals only close to predicted contour
- Neighbor contour points produce similar gradients
- Dense SDF computation is expensive (Repeated rendering and Direct transform)

Are dense computations necessary?

Contour prediction



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Observations:

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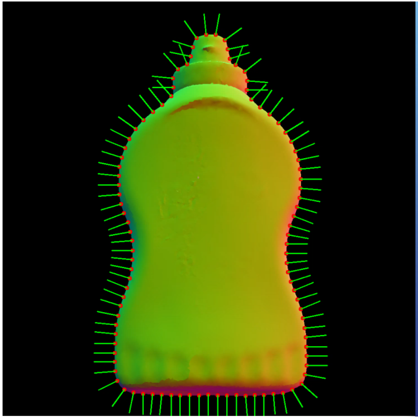
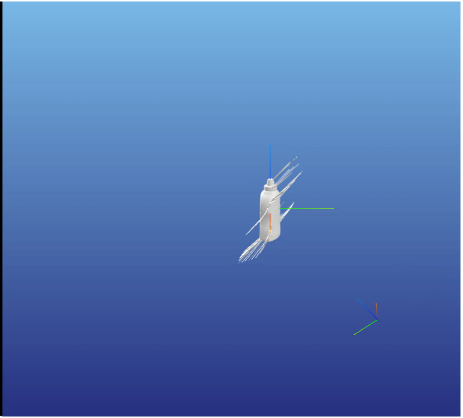
Sparse Region based method [Keh+17]

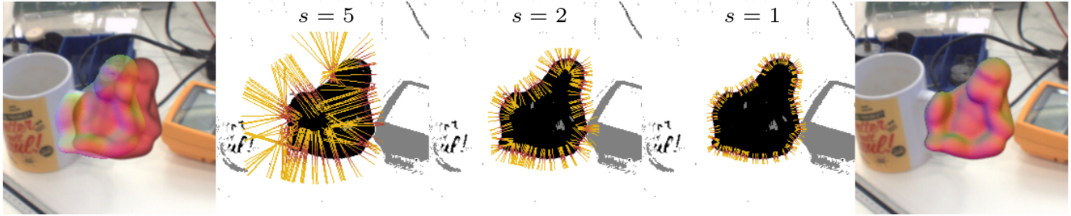
- Idea1: Sample contour control points
- Idea2: Precomputation of template views

Sparse view precomputations

Typically by using a geodesic polyhedron (e.g. 2562 views)

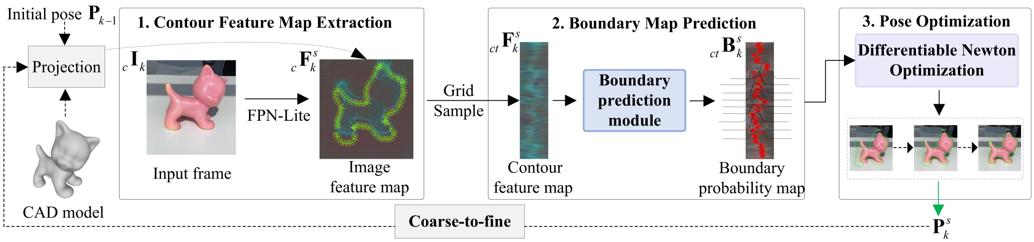



Correspondance lines reformulation



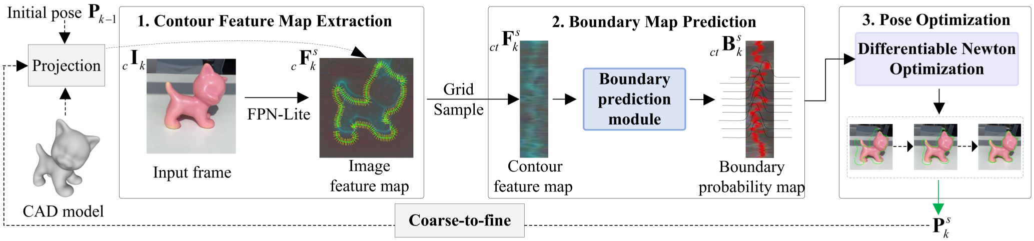
Correspondance lines, coarse to fine iterations [Sto+20]

Hybrid learning + optimization region based tracking



Deep Active Contour for Real-time 6-DoF Object Tracking [Wan+23]

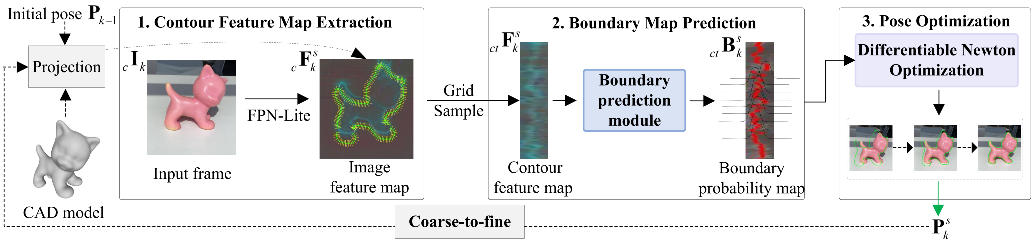
Hybrid learning + optimization region based tracking



Deep Active Contour for Real-time 6-DoF Object Tracking [Wan+23]

- Replace histograms by learning contour probability prediction

Hybrid learning + optimization region based tracking



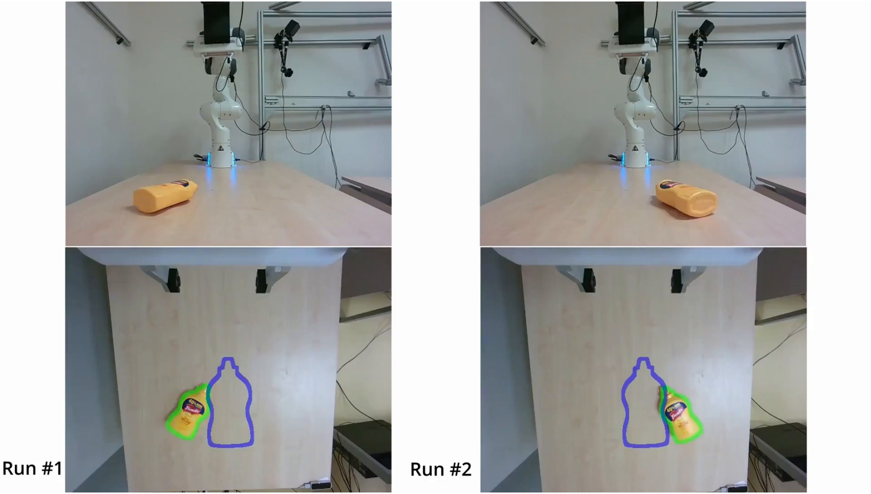
Deep Active Contour for Real-time 6-DoF Object Tracking [Wan+23]

- Replace histograms by learning contour probability prediction
- Trained end to end with differentiable optimization

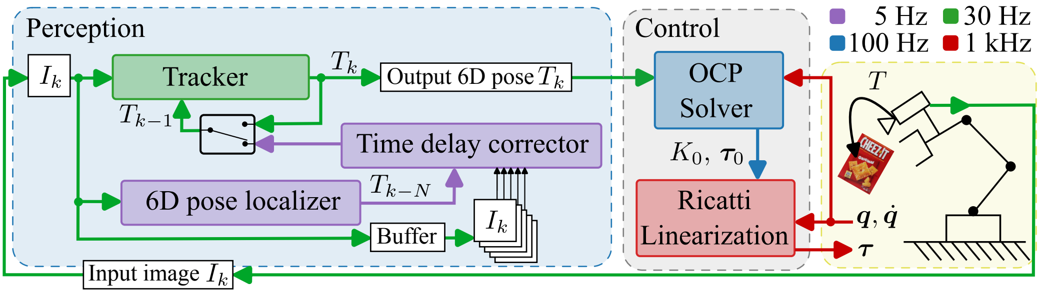
Object localization and tracking

An architecture for vision-based feedback control

Object tracking with manipulator

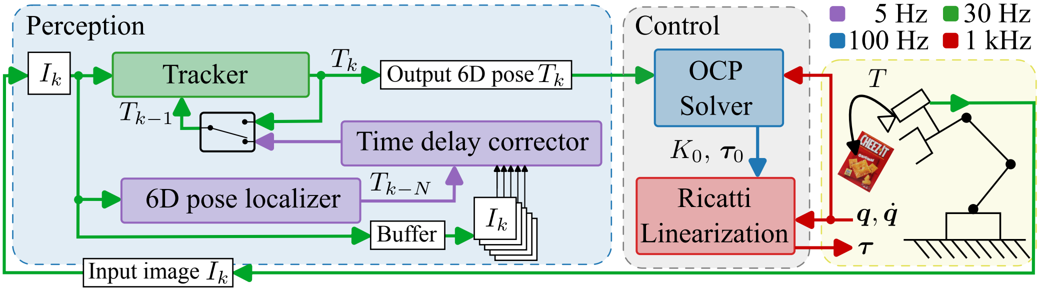


System architecture



Object localization and tracking architecture [Fou+23]

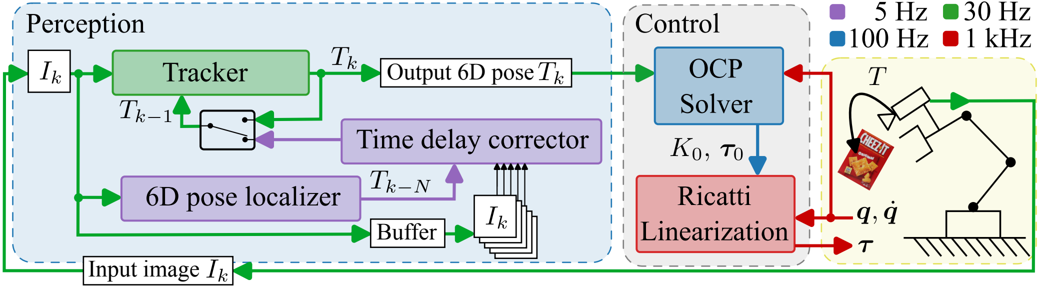
System architecture



Object localization and tracking architecture [Fou+23]

- Asynchronous object localization and tracking

System architecture



Object localization and tracking architecture [Fou+23]

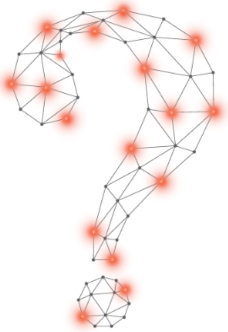
- Asynchronous object localization and tracking
- Torque level MPC (crocoddyl) with Riccatti based feedback

Practical session

Practical session

- Pose detection
  - 2D detection
  - CosyPose
  - Megapose
- Pose tracking
  - Recorded sequences
  - Webcam

Questions and Answers



Contact details

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