Autonomous and Mobile Robotics

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Vision-Based Localization and Navigation for Humanoid Robots

(slides prepared by Antonio Paolillo and Lorenzo Rosa)

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vision in humanoid robotics

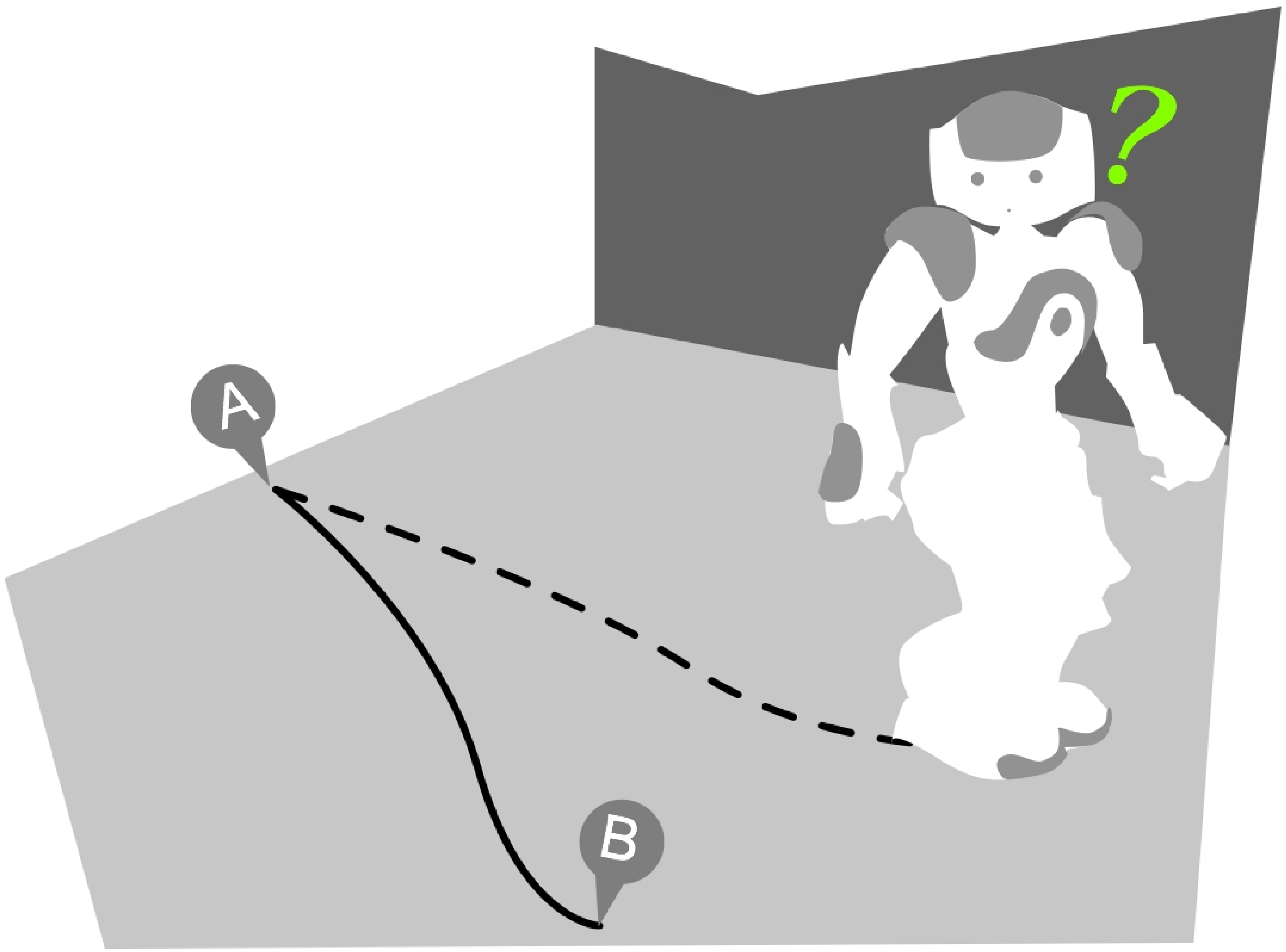
- vision augments the exteroceptive sensory capability of a robot
- robots can extract valuable information about the environment through the image processing
- humanoid locomotion tasks can be converted into visual tasks
- visual feedback provides robust (and human-like) behavior

vision-based methods for humanoids

- vision-based localization system
  - system based on simple kinematic odometry (dead reckoning) is not accurate
  - reliable localization system does not exist for humanoid robots!

- vision-based navigation controller
  - autonomous and safe navigation in unknown environment can be obtained with visual information

vision-based localization for humanoids
motivations



vision-based localization for humanoids

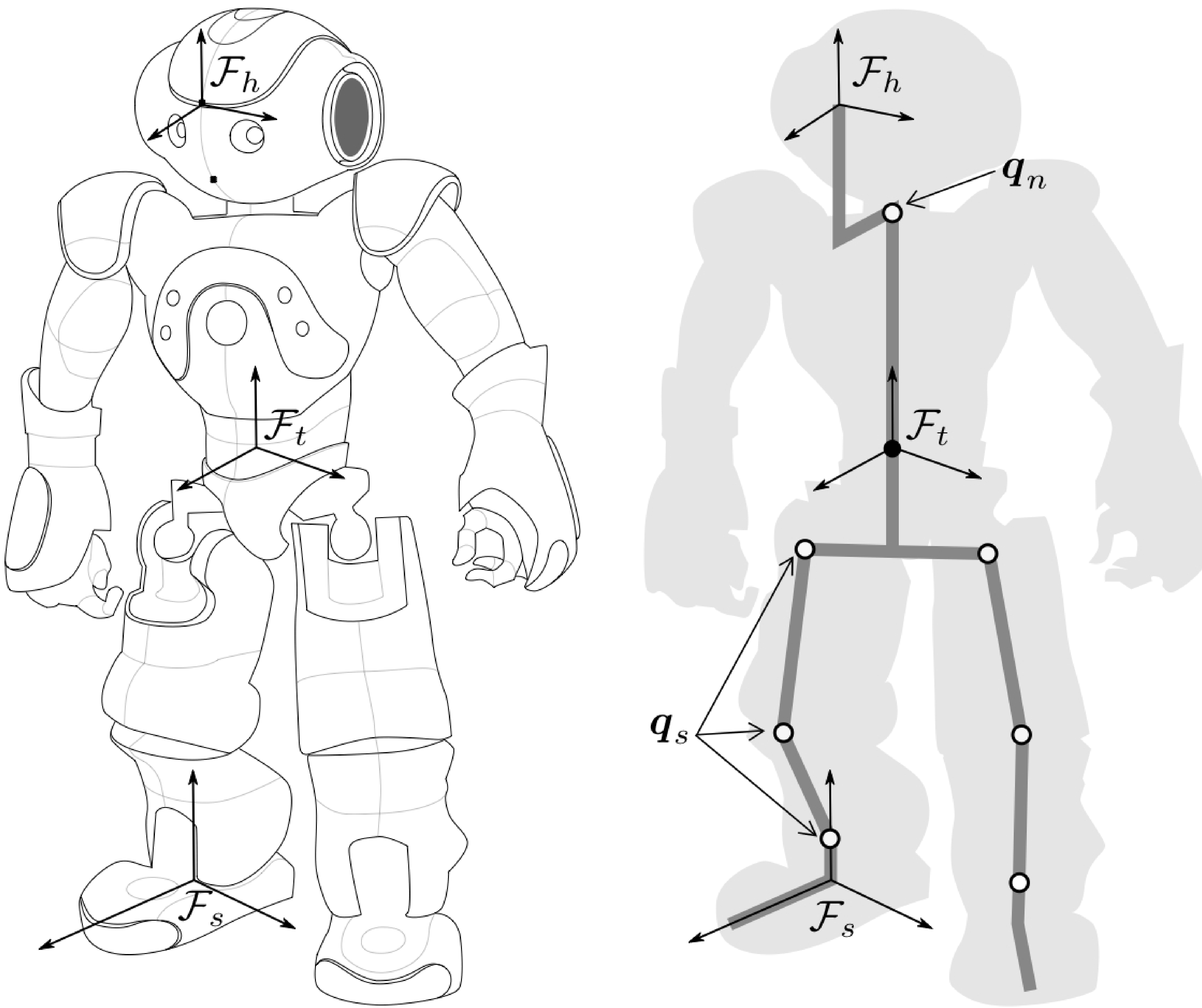
motivations

vision-based localization for humanoids

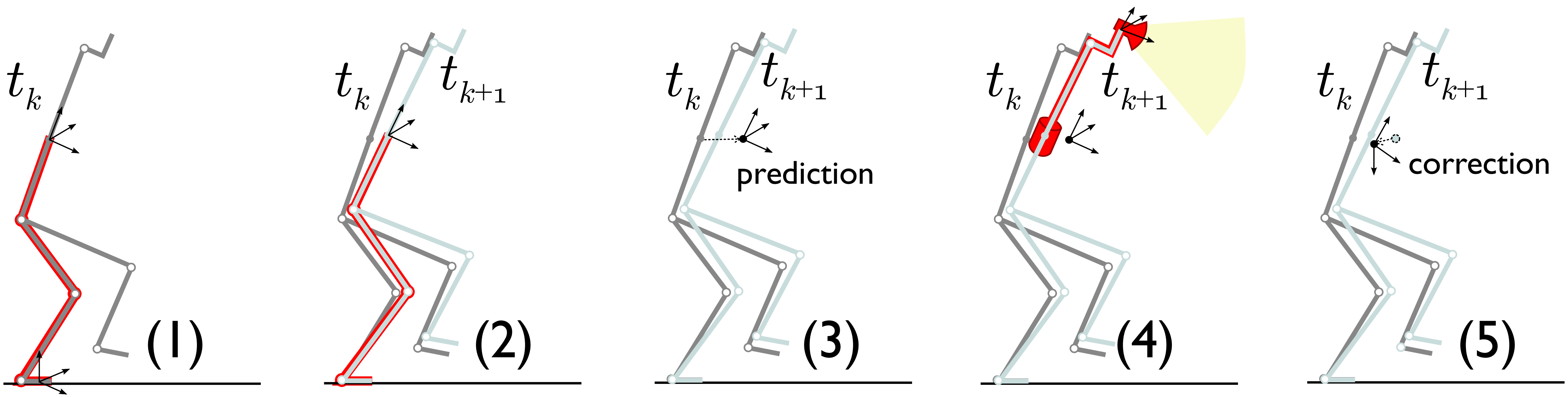
idea

- develop a visual EKF-based localization method for improving built-in odometry in humanoids (e.g., NAO)
- prediction of the torso pose is made using a purely kinematic model and encoder data
- correction is computed from measurements: head pose given by an off-the-shelf V-SLAM algorithm (PTAM) + torso orientation coming from the IMU
- foot pressure sensors allow to synchronize the EKF with the walking gait

vision-based localization for humanoids
frames of interest



vision-based localization for humanoids
EKF steps



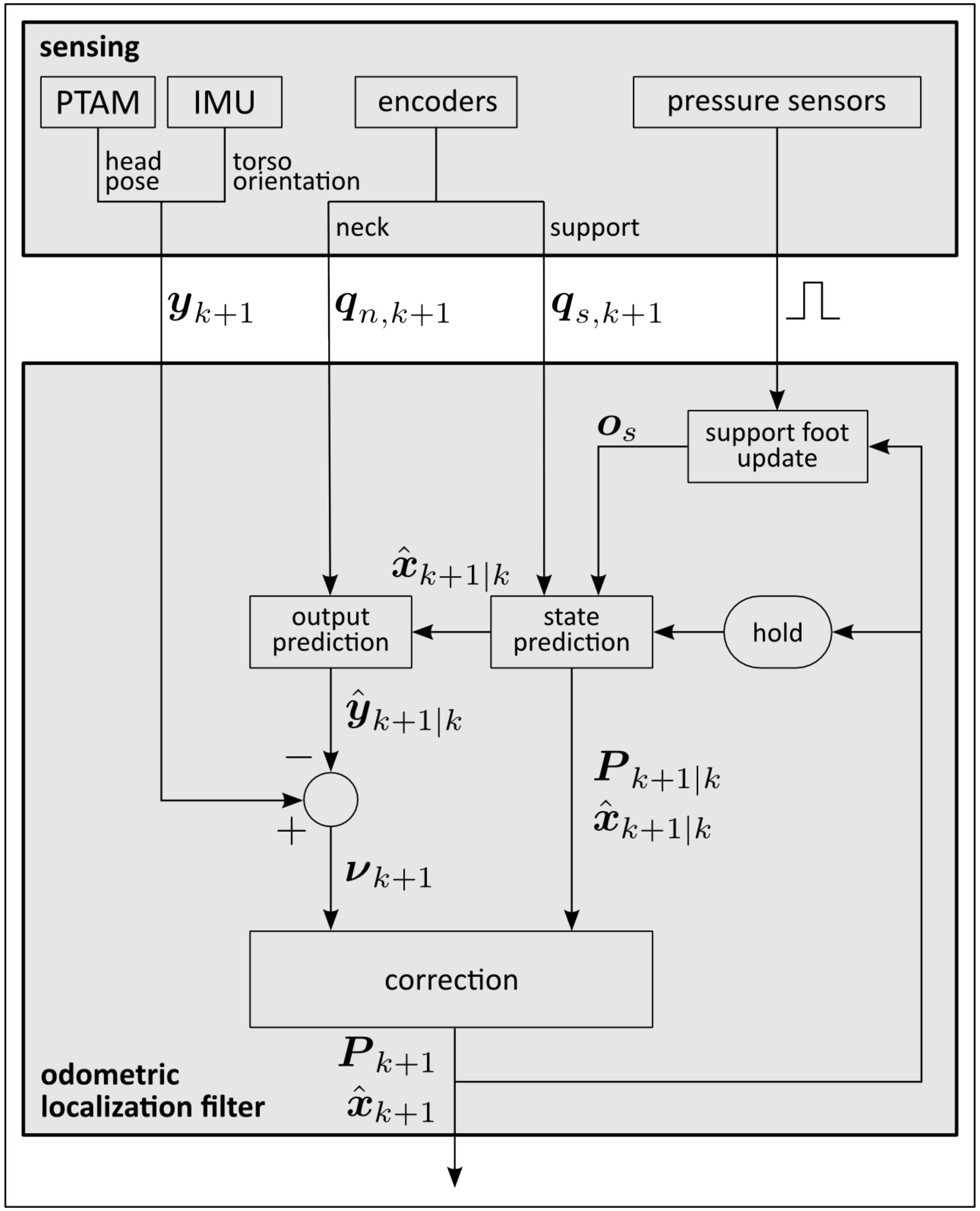
1. read support joints $\boldsymbol{q}_{s,k}$ at t_k
2. read support joints at t_{k+1} and compute $\Delta\boldsymbol{q}_{s,k} = \boldsymbol{q}_{s,k} - \boldsymbol{q}_{s,k-1}$
3. compute prediction using the support foot orientation $\boldsymbol{o}_s$

$$\hat{\boldsymbol{x}}_{k+1|k} = \hat{\boldsymbol{x}}_k + \boldsymbol{J}(\boldsymbol{q}_{s,k}, \boldsymbol{o}_s)\Delta\boldsymbol{q}_{s,k}$$

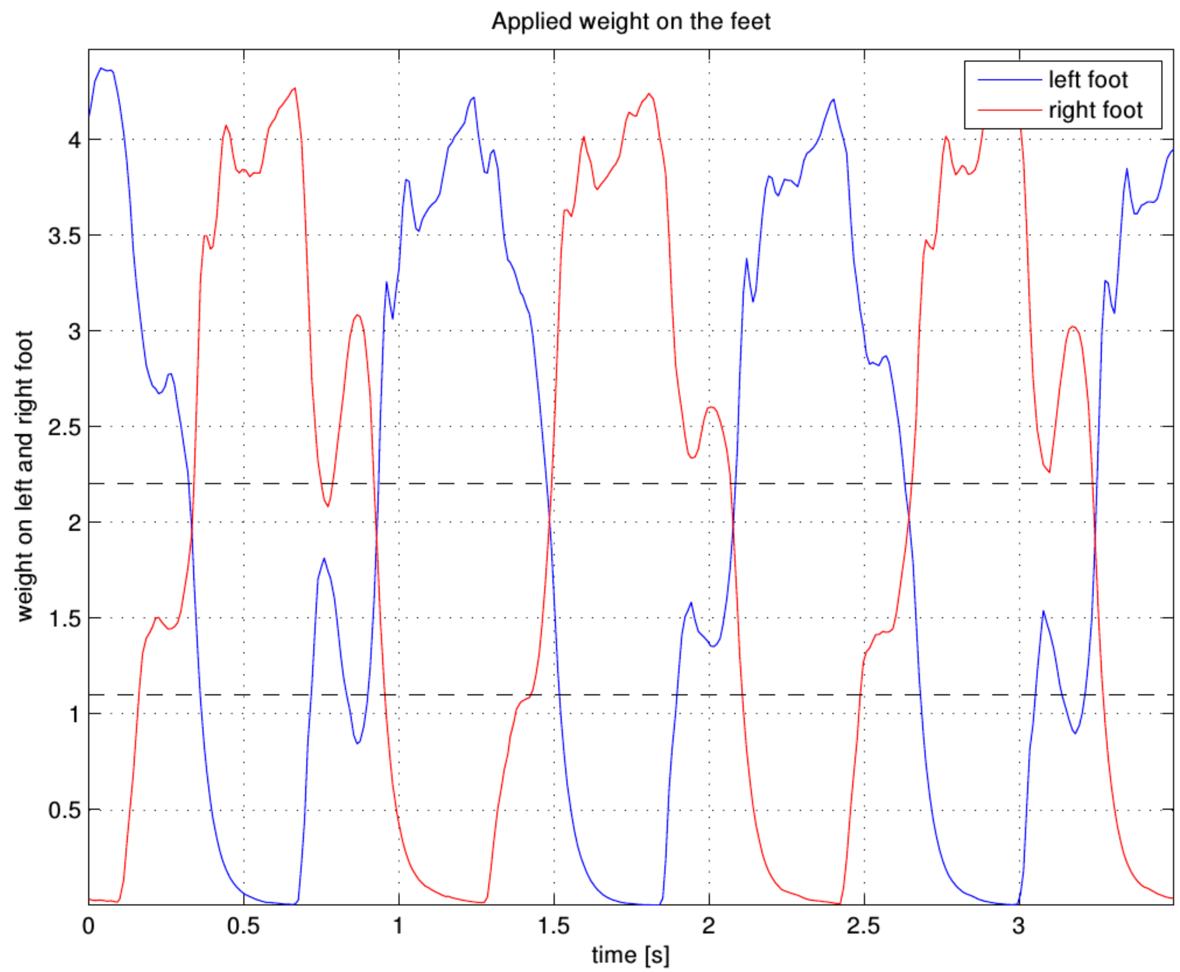
4. get measurements $\boldsymbol{y}_{k+1}$ from V-SLAM and IMU
5. compute correction based on the innovation u_{k+1}

$$\hat{\boldsymbol{x}}_{k+1} = \hat{\boldsymbol{x}}_{k+1|k} + \boldsymbol{G}_{k+1}\boldsymbol{u}_{k+1}$$

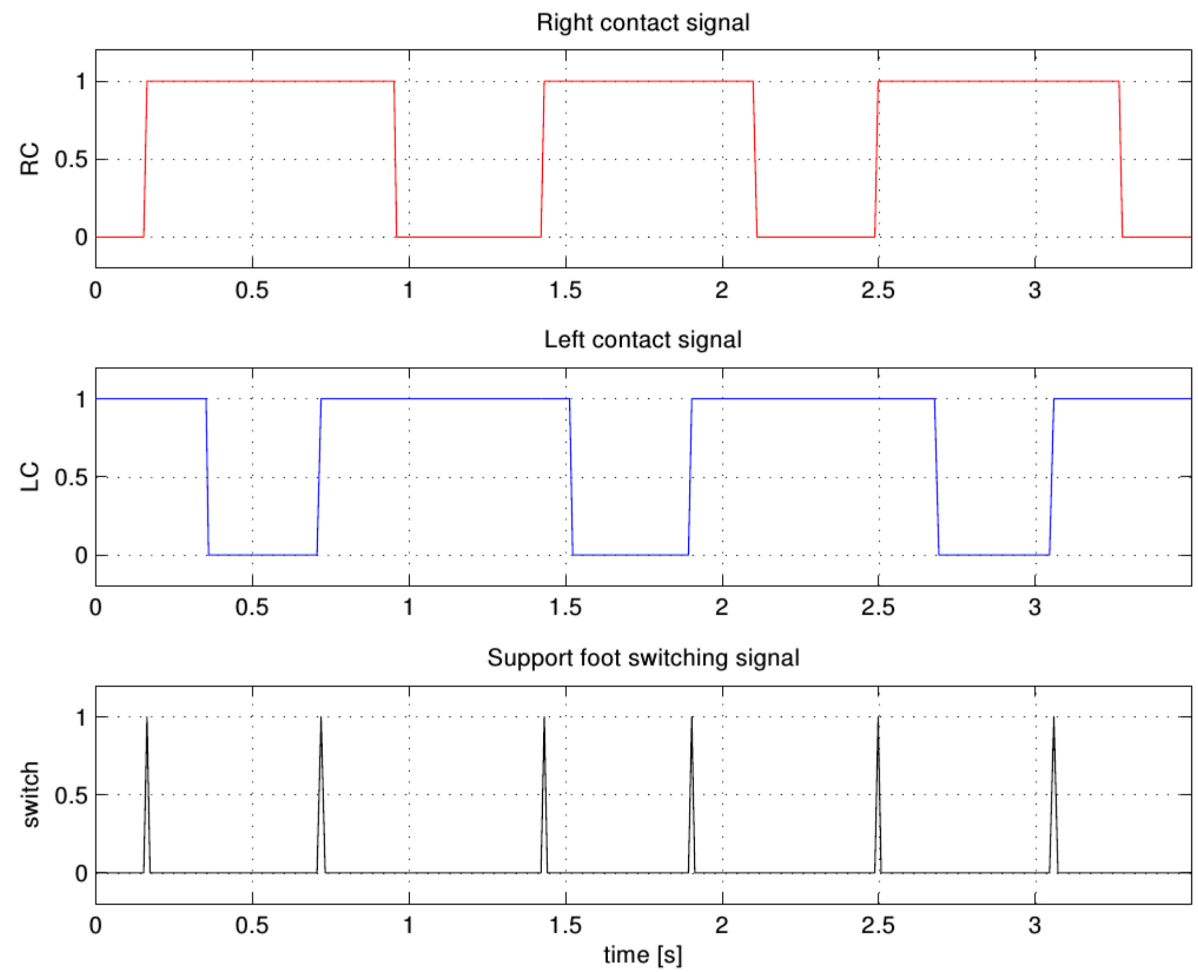
vision-based localization for humanoids
block diagram



vision-based localization for humanoids
foot pressure sensors



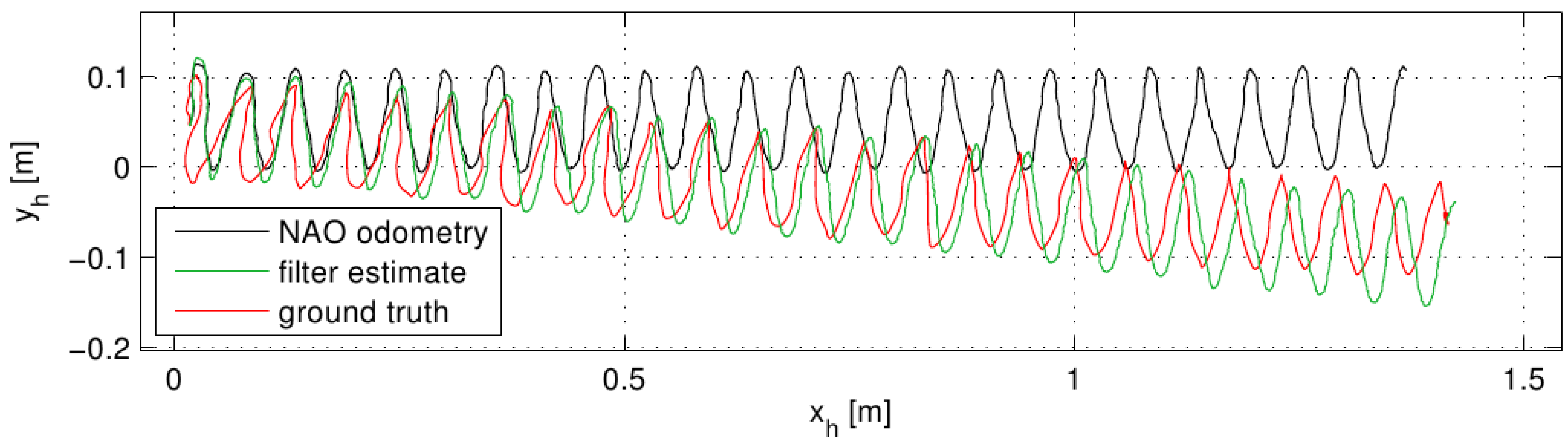
raw signals



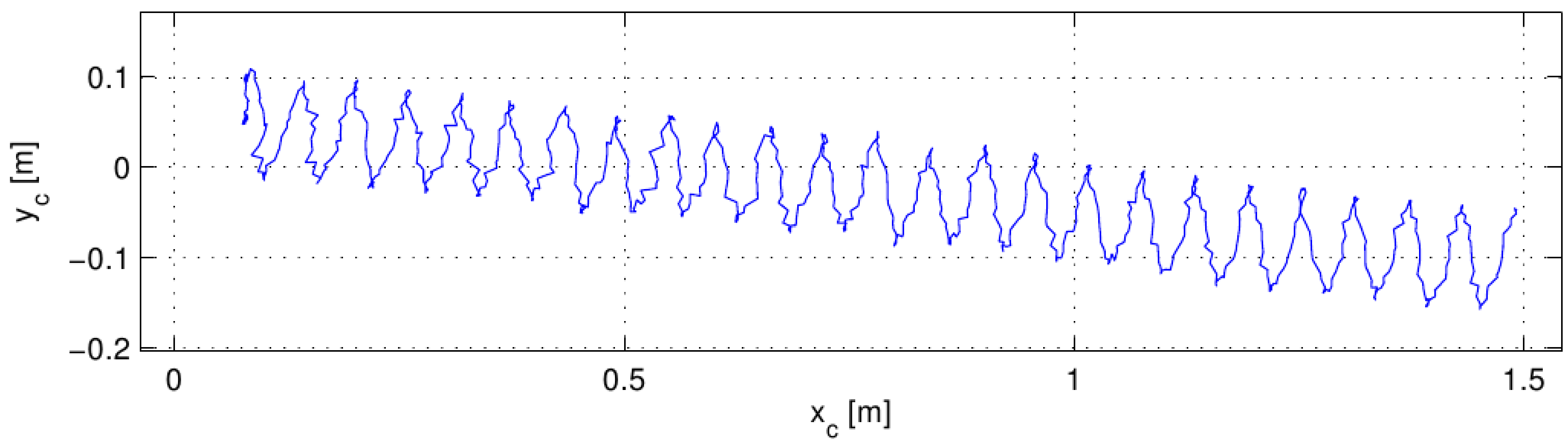
processed output

vision-based localization for humanoids
experimental results – simple motion

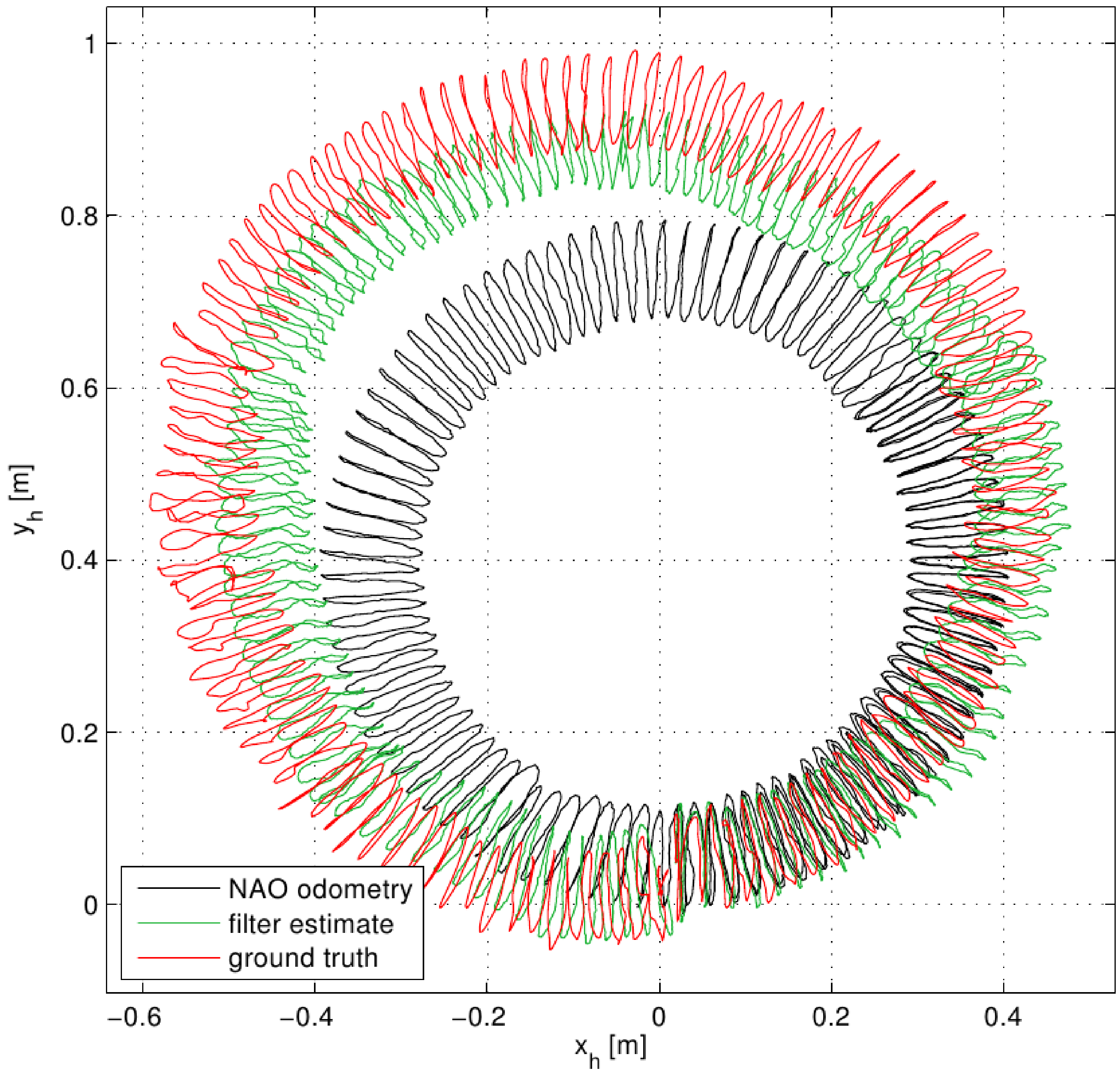
robot motion (top view)



V-SLAM (Parallel Ttracking And Mapping - PTAM)

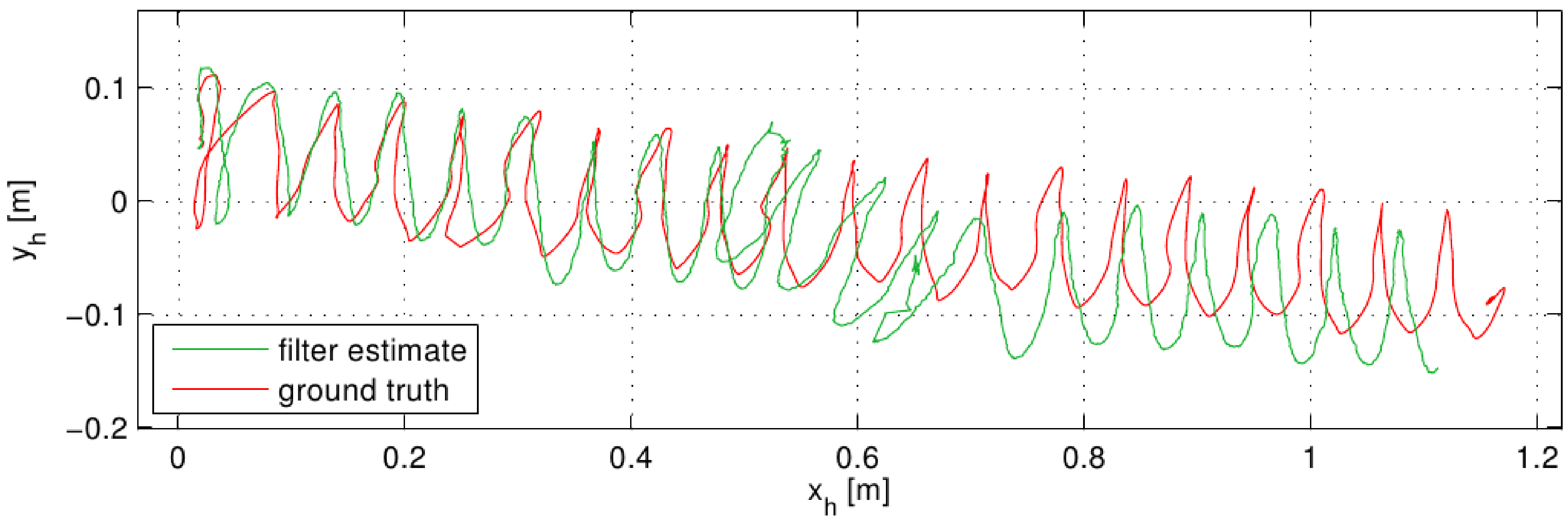


vision-based localization for humanoids
experimental results – circular motion

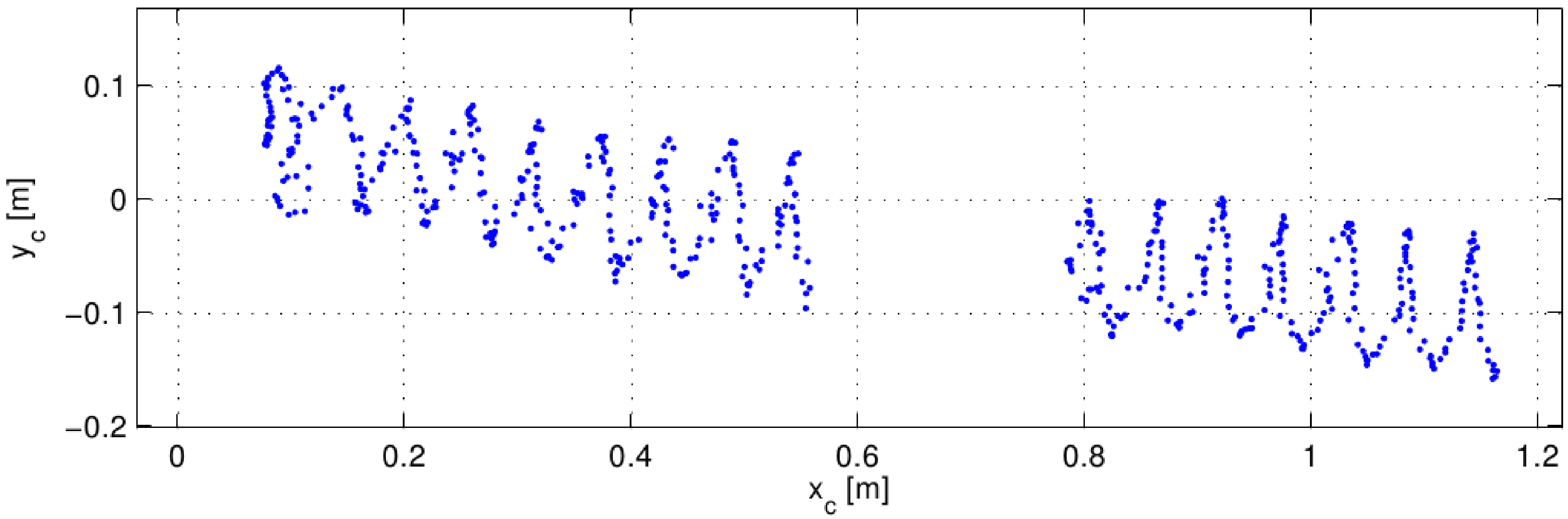


vision-based localization for humanoids
experimental results – blind navigation

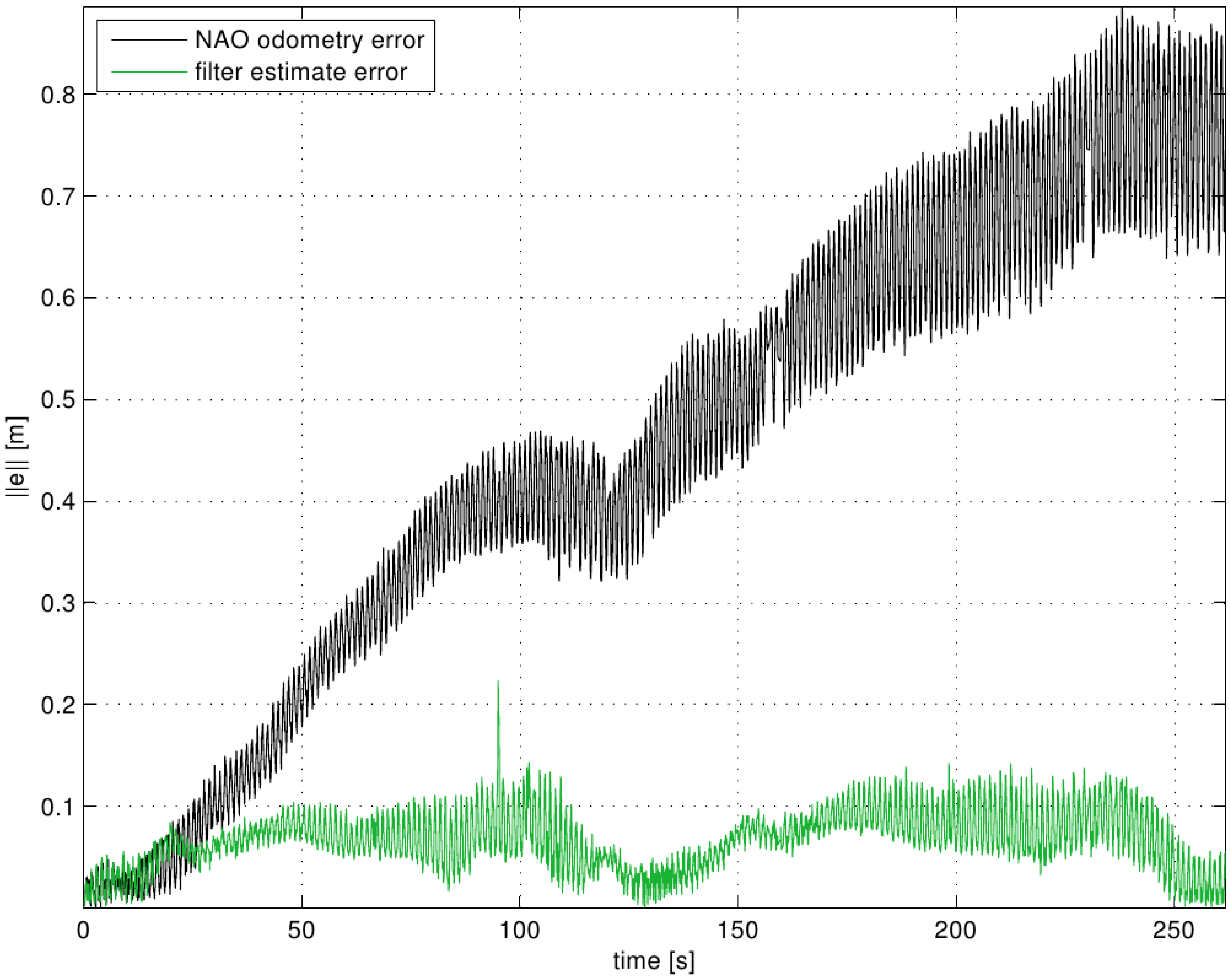
robot motion (top view)



V-SLAM (Parallel Ttracking And Mapping - PTAM)



vision-based localization for humanoids
experimental results – double circle



vision-based localization for humanoids
trajectory control – idea

humanoid robots can be controlled as unicycle robots
by passing forward and steering velocity

- design a feasible desired trajectory for the robot
- use the estimated output to feed a trajectory controller designed for unicycle robots

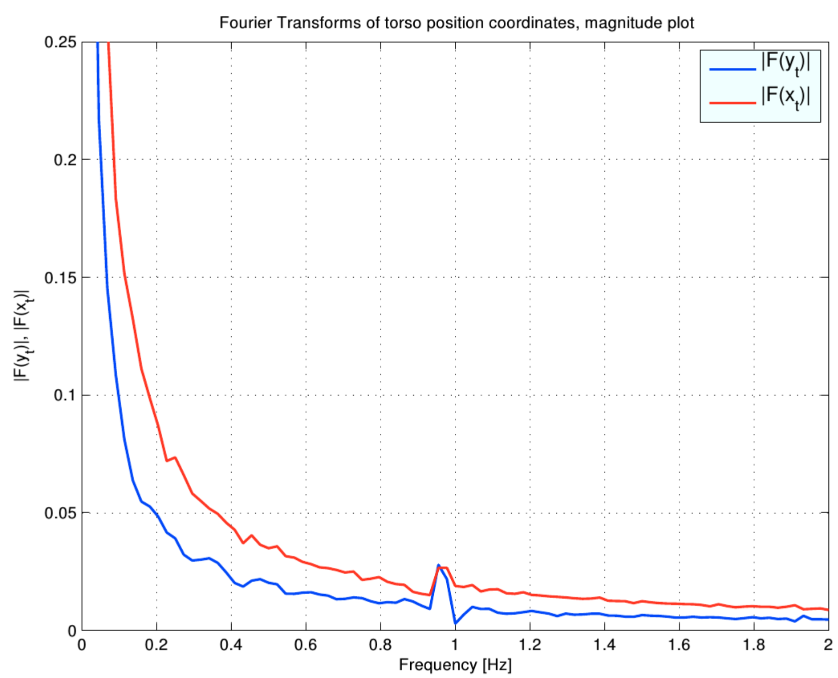
ISSUES

- sway motion due to walking gait must be removed

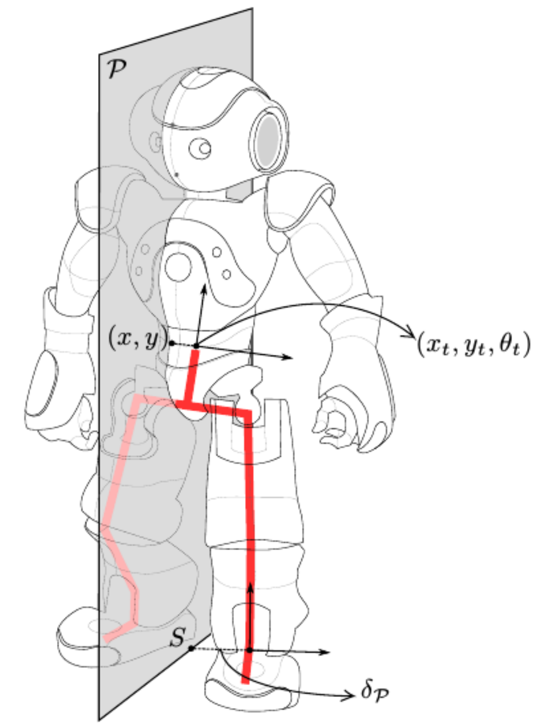
vision-based localization for humanoids

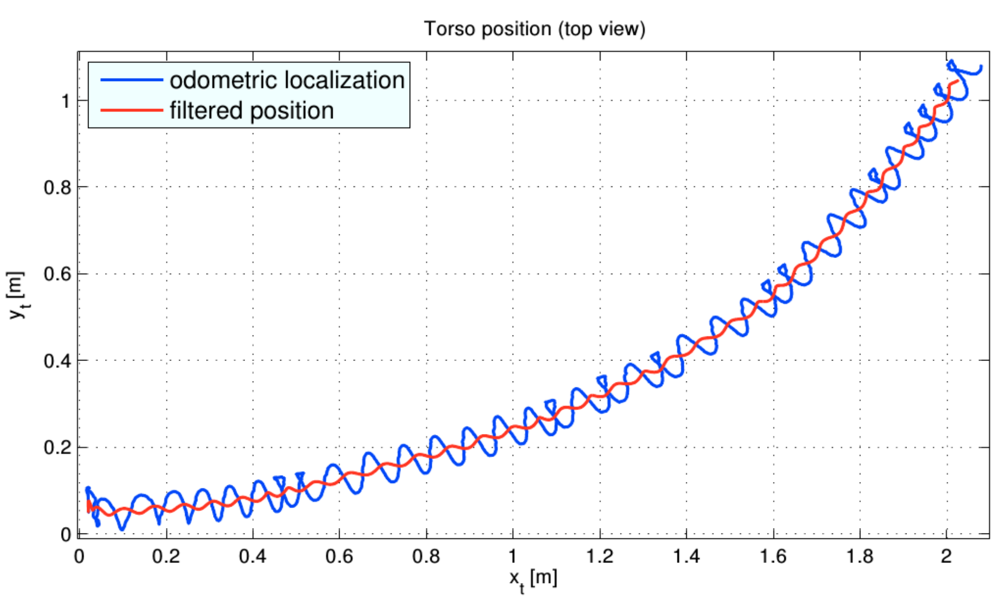
cancellation of the sway motion

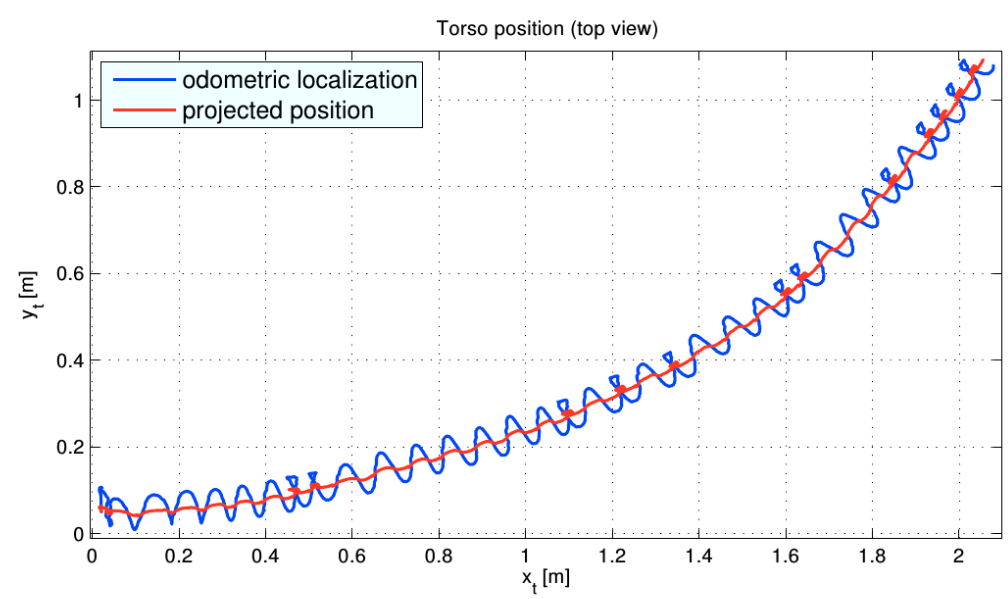
frequency filter (lowpass)



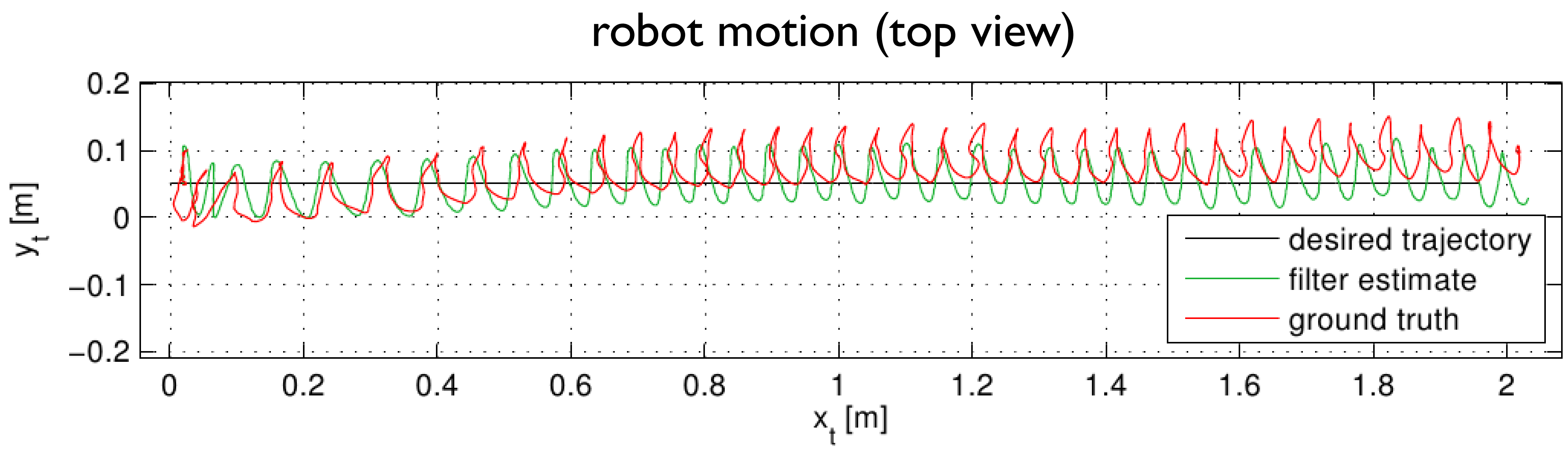
kinematic computation

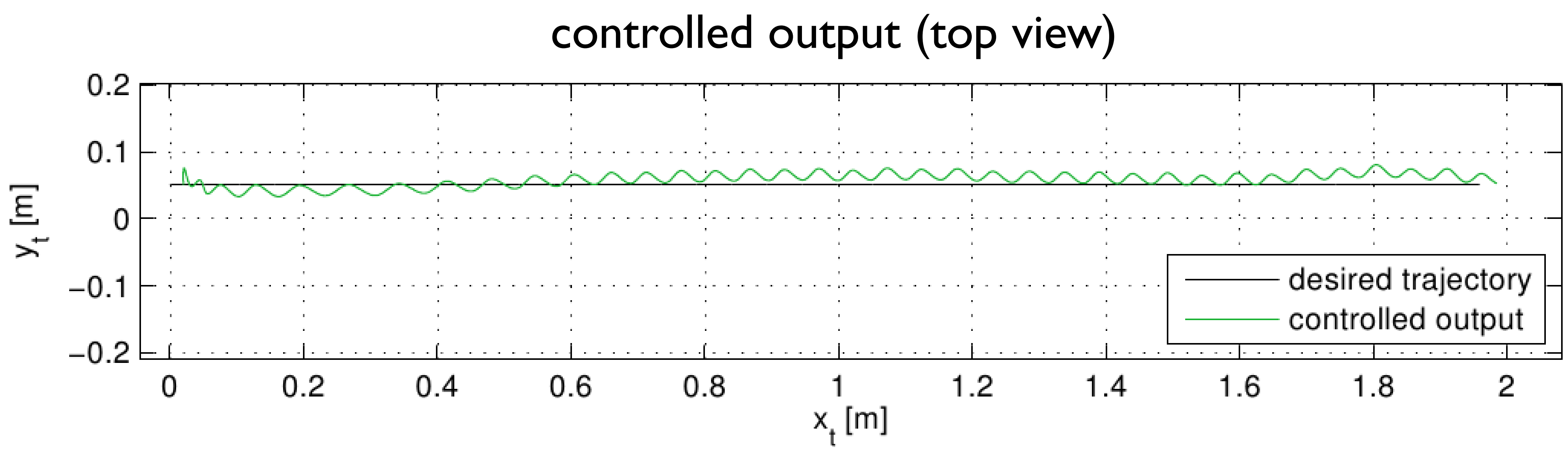






vision-based localization for humanoids
trajectory control – experimental results

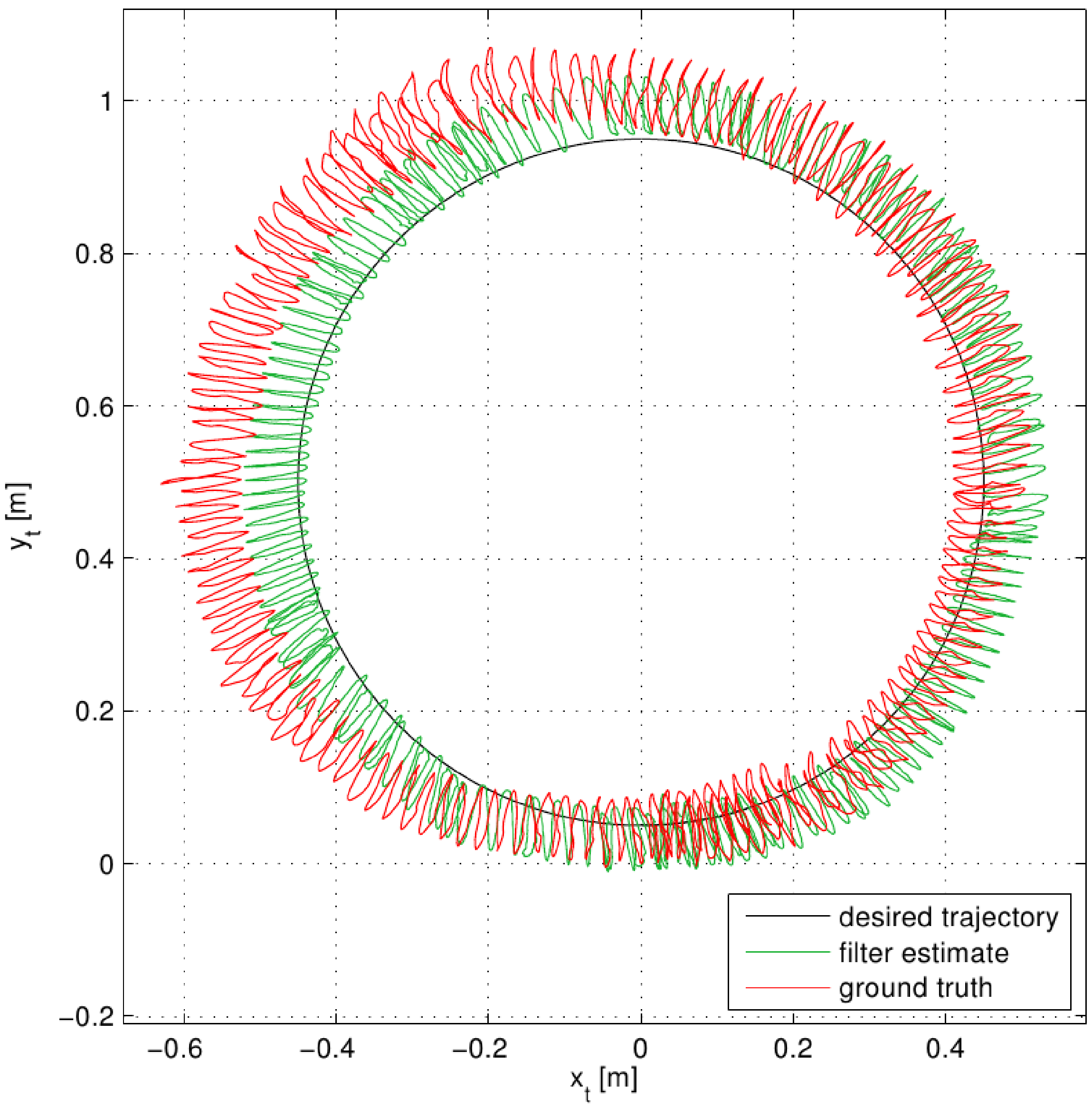




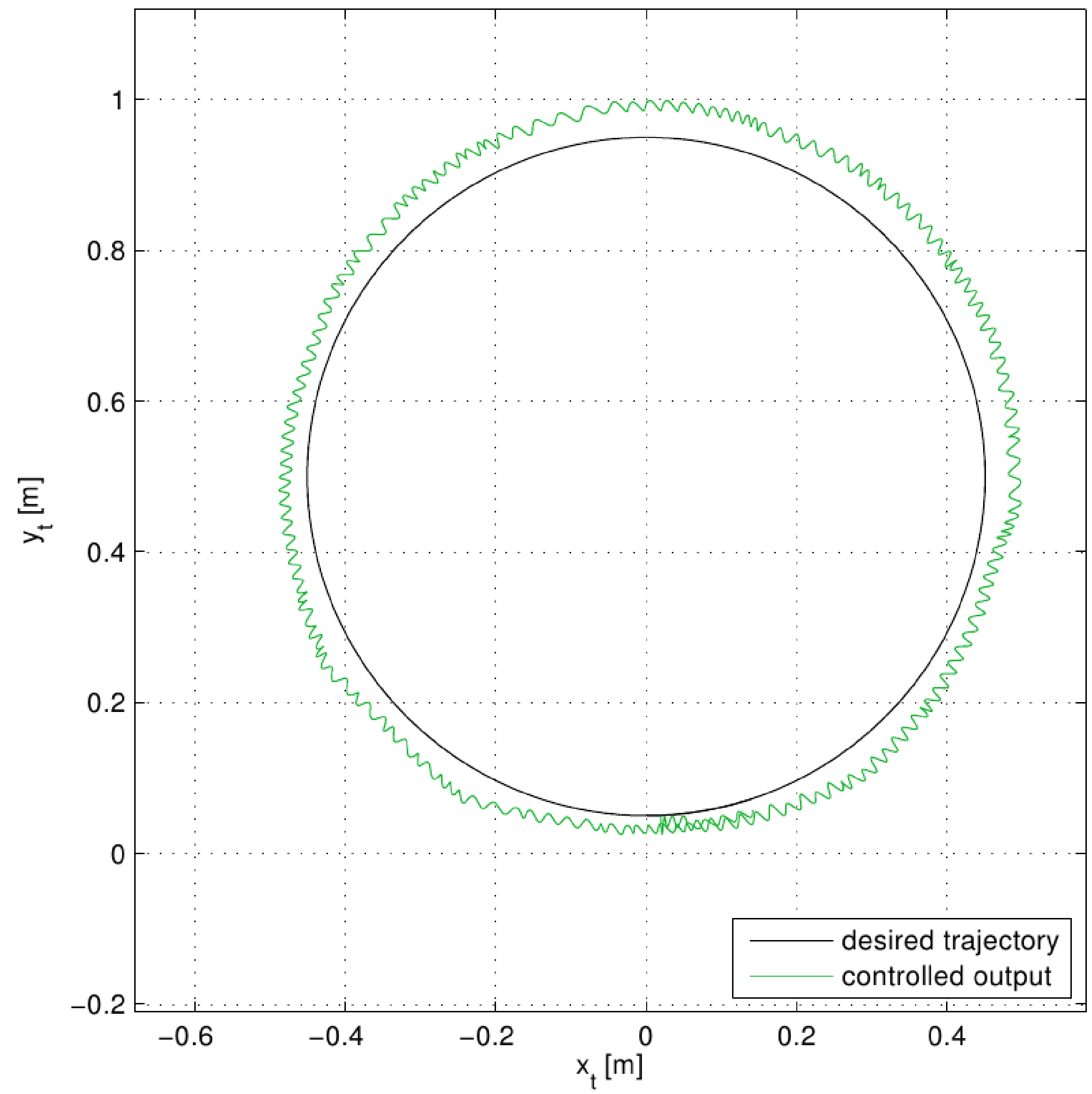
vision-based localization for humanoids

trajectory control – experimental results

robot motion (top view)



controlled output (top view)

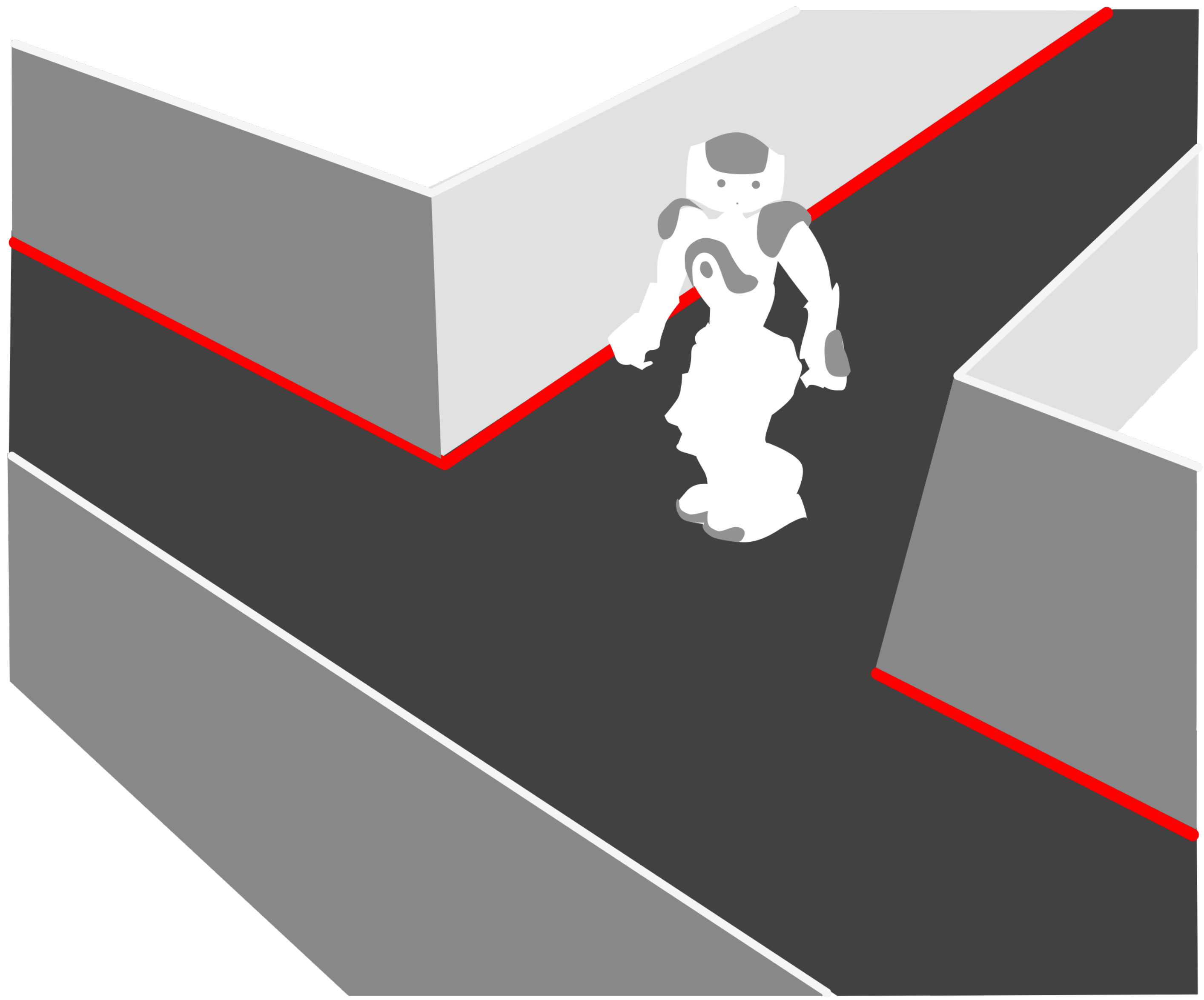


vision-based localization for humanoids
experimental results

G. Oriolo, A. Paolillo, L. Rosa, M. Vendittelli, *Vision-Based Odometric Localization for Humanoids using a Kinematic EKF*, 2012 IEEE-RAS International Conference on Humanoid Robots, Osaka, Japan, Nov-Dec 2012.

G. Oriolo, A. Paolillo, L. Rosa, M. Vendittelli, *Vision-Based Trajectory Control for Humanoid Navigation*, 2013 IEEE-RAS International Conference on Humanoid Robots, Atlanta, GA, Oct 2013.

vision-based navigation for humanoids

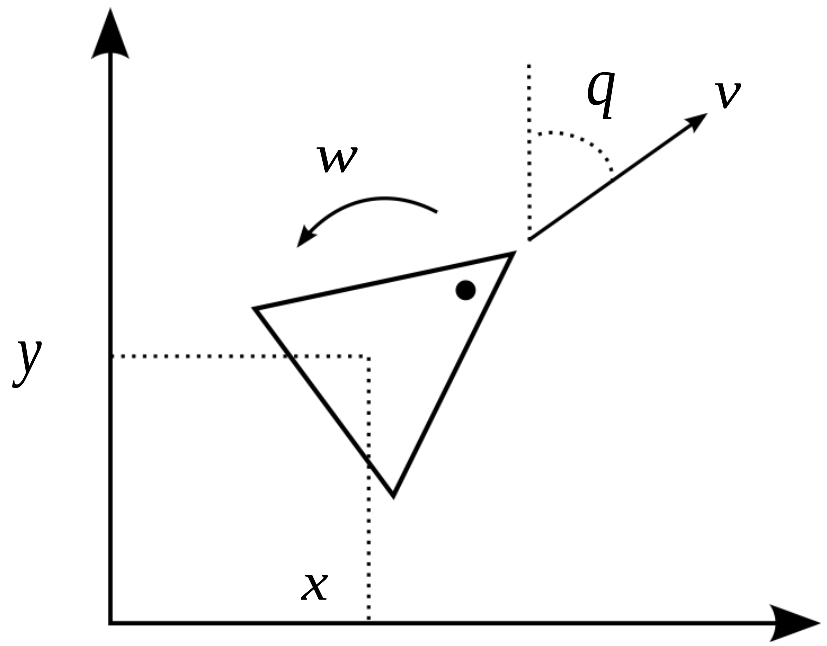


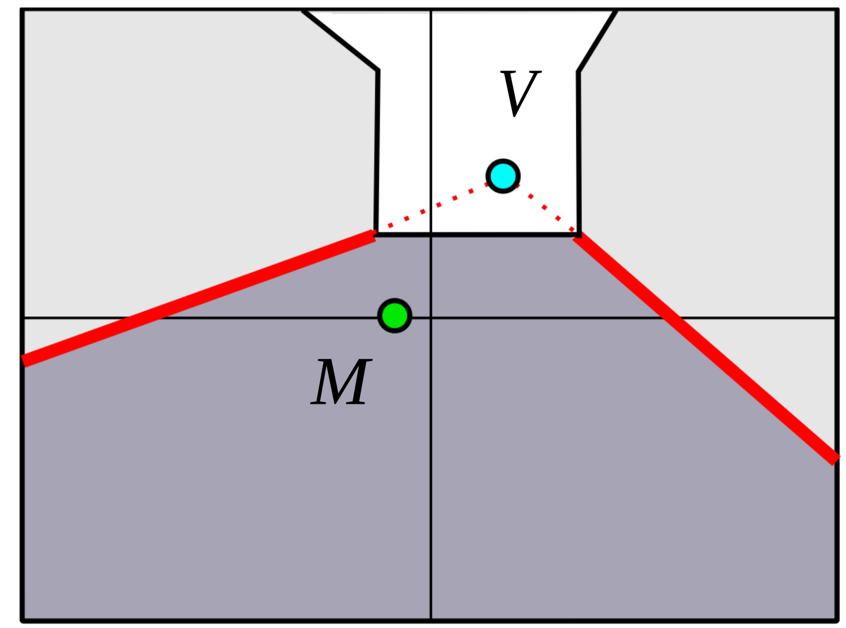
vision-based navigation for humanoids
objective and approach

- robust navigation for humanoid robots needs exteroceptive feedback
  - most navigation tasks can be conveniently encoded into visual task
- for human-like behaviour, on long-distance walks, the orientation of humanoid should be tangent to the path
  - adopting unicycle mobility model allows to exploit existing results on visual navigation for wheeled mobile robots

vision-based navigation for humanoids

visual control law





- mobility model

$$\dot{x} = v \sin q$$
$$\dot{y} = v \cos q$$
$$\dot{q} = \omega$$

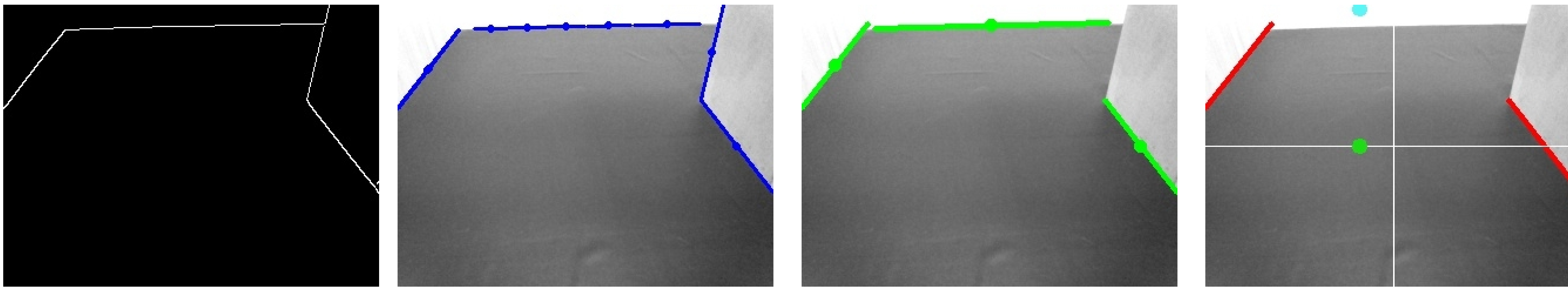
- visual features

$$x_V = k_1 \tan q$$
$$x_M = k_2 \frac{x}{\cos q} + k_3 \tan q$$

- steering controller (constant linear velocity)

$$\omega = \frac{k_1}{k_1 k_3 + x_M x_V} \left(-\frac{k_2 v}{k_1} x_V - k_p x_M \right)$$

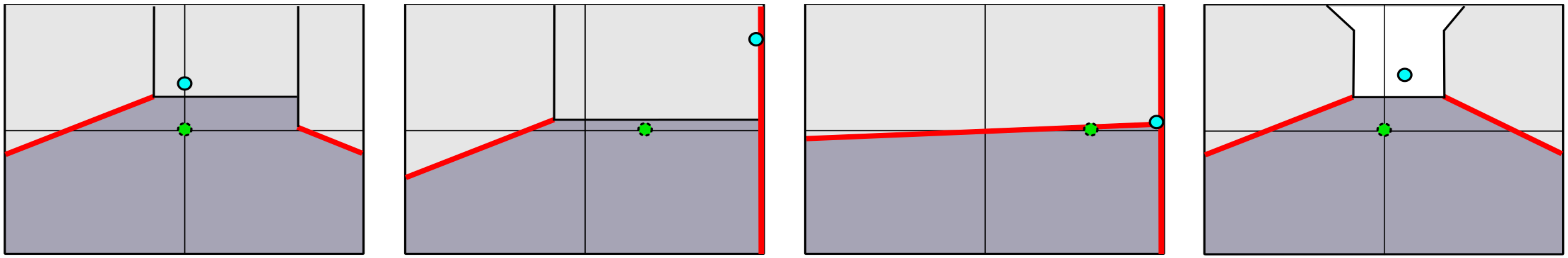
vision-based navigation for humanoids
image processing



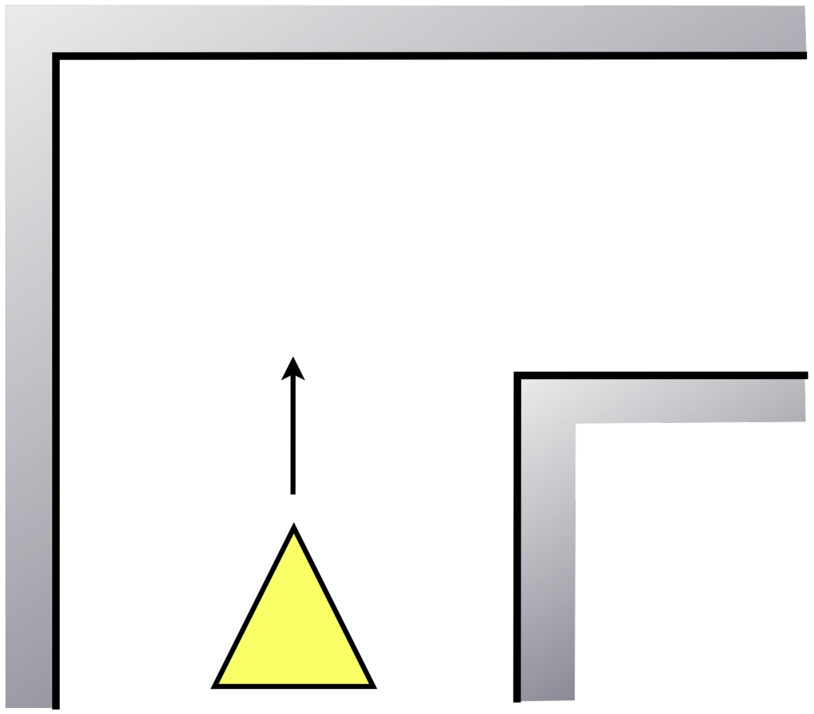
(1) (2) (3) (4)

1. edge detection
2. line detection
3. line merging
4. guideline selection and feature computation

vision-based navigation for humanoids
negotiating a curve

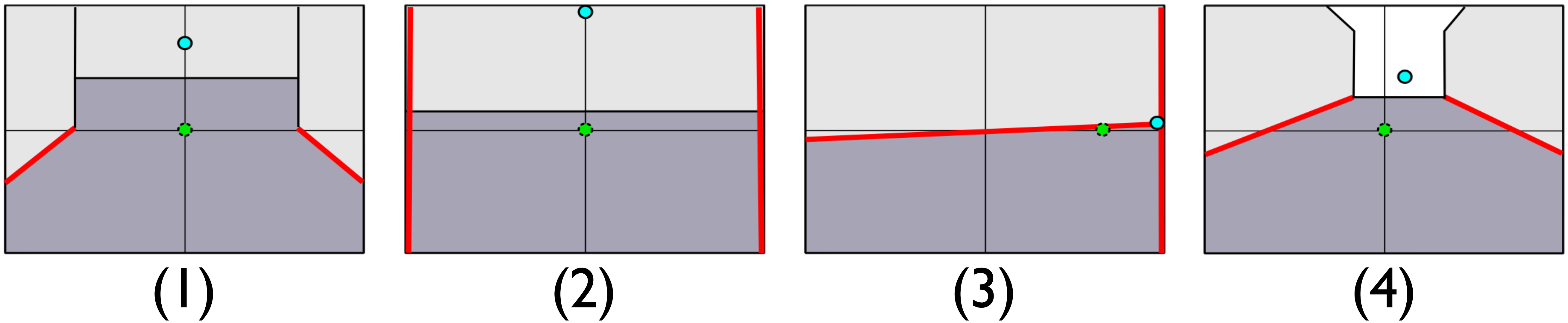


(1) (2) (3) (4)

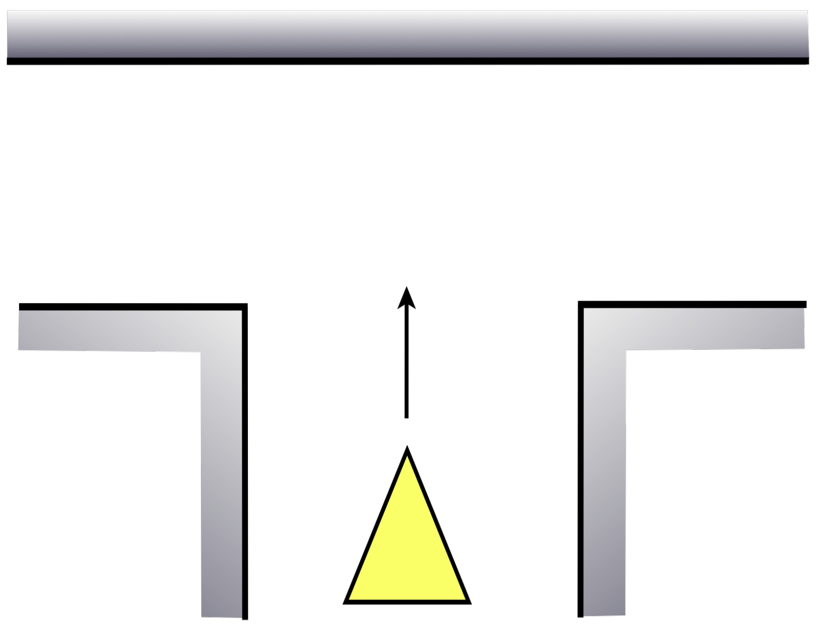


- one of the corridor guidelines gradually disappears in correspondence of a turn: (1)
- the corresponding side of the image is used as a virtual feature: (2) and (3)
- x_V and x_M move toward the turn direction and force the robot to turn

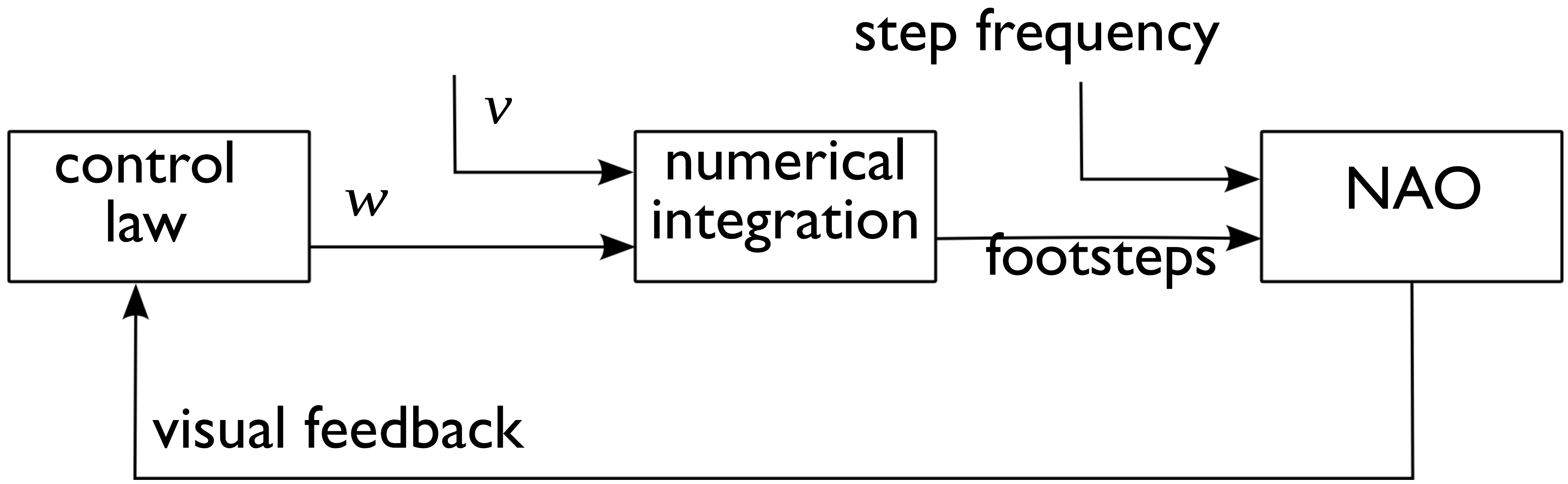
vision-based navigation for humanoids
turning at a T-junction



- both corridor guidelines gradually disappear in the proximity of a T-junction: (1)
- both sides of the image become virtual features (2)
- turning is triggered by the horizontal line in the image plane: (3)
- after the turn, both guidelines are recovered and the robot resumes normal navigation: (4)



vision-based navigation for humanoids
from unicycle to humanoid



- humanoids are endowed by omnidirectional walk capability
- unicycle commands can be converted into admissible inputs for the low-level locomotion controller
- such control input can be feed to the NAO robot by using the built-in method setWalkTargetVelocity

vision-based navigation for humanoids
experimental results

A. Faragasso, G. Oriolo, A. Paolillo, M. Vendittelli, *Vision-based corridor navigation for humanoid robots,* 2013 IEEE International Conference on Robotics and Automation, Karlsruhe, Germany, 7-9 May 2013.