Event-Based Visual Servoing for Human-Robot Navigation using Reinforcement Learning

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Motivation

- Efficient Human-Robot Interaction in dynamic environments demands advanced sensory processing and adaptive control.
- This work leverages event cameras and Reinforcement Learning to enhance human tracking and obstacle avoidance in social robot navigation.

Human-centered social robot: Bender

Fig. 1 - Bender: A General-Purpose Social Robot for HRI.

Human tracking and obstacle avoidance

- This work employs a Pioneer 3-AT base with 2D Hokuyo LIDAR, DAVIS346 event camera, RealSense.

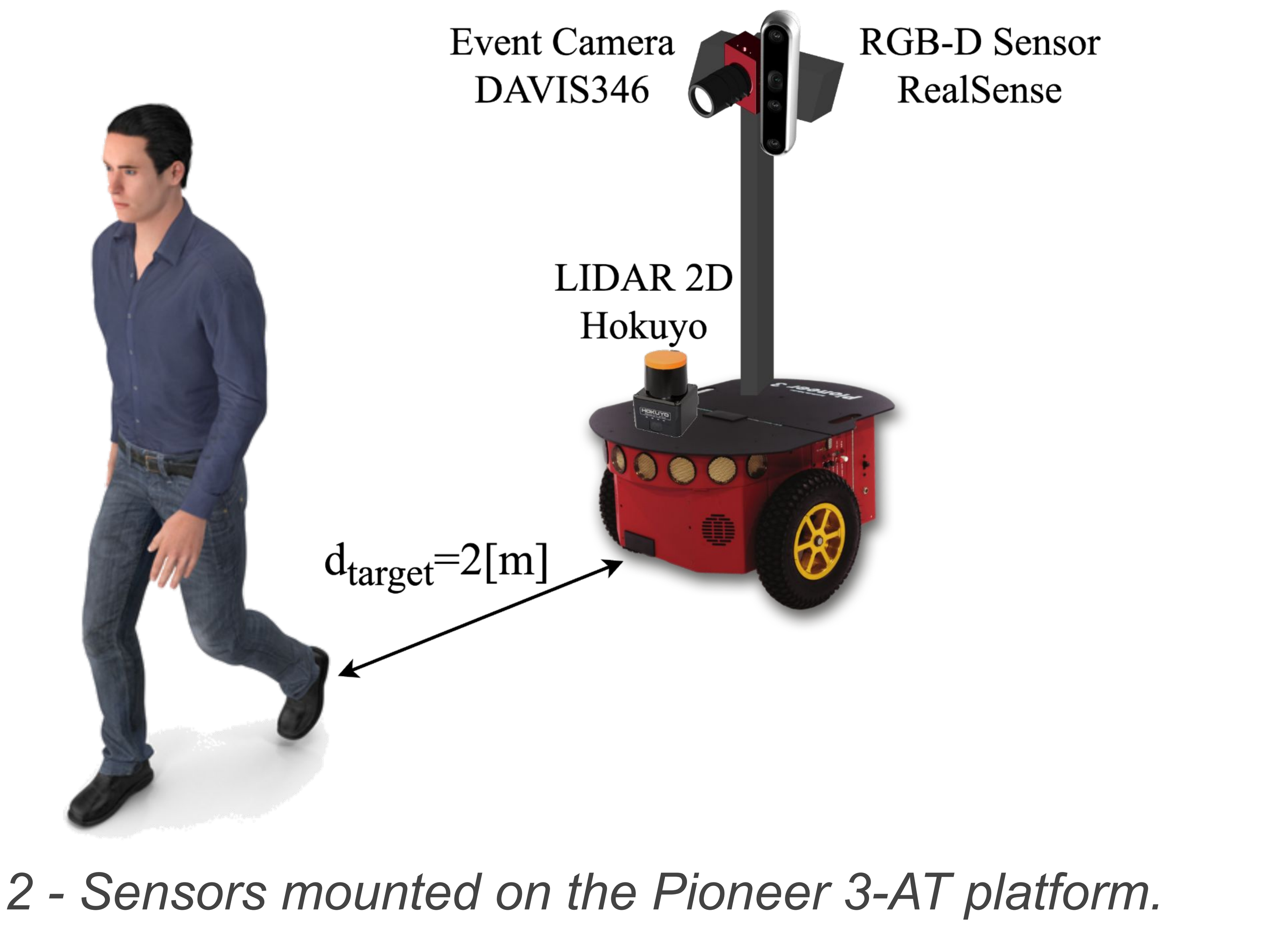

Fig. 2 - Sensors mounted on the Pioneer 3-AT platform.

Our proposal: Event-based visual servoing

- This work proposes an event-based visual servo controller for human-following in social robots.

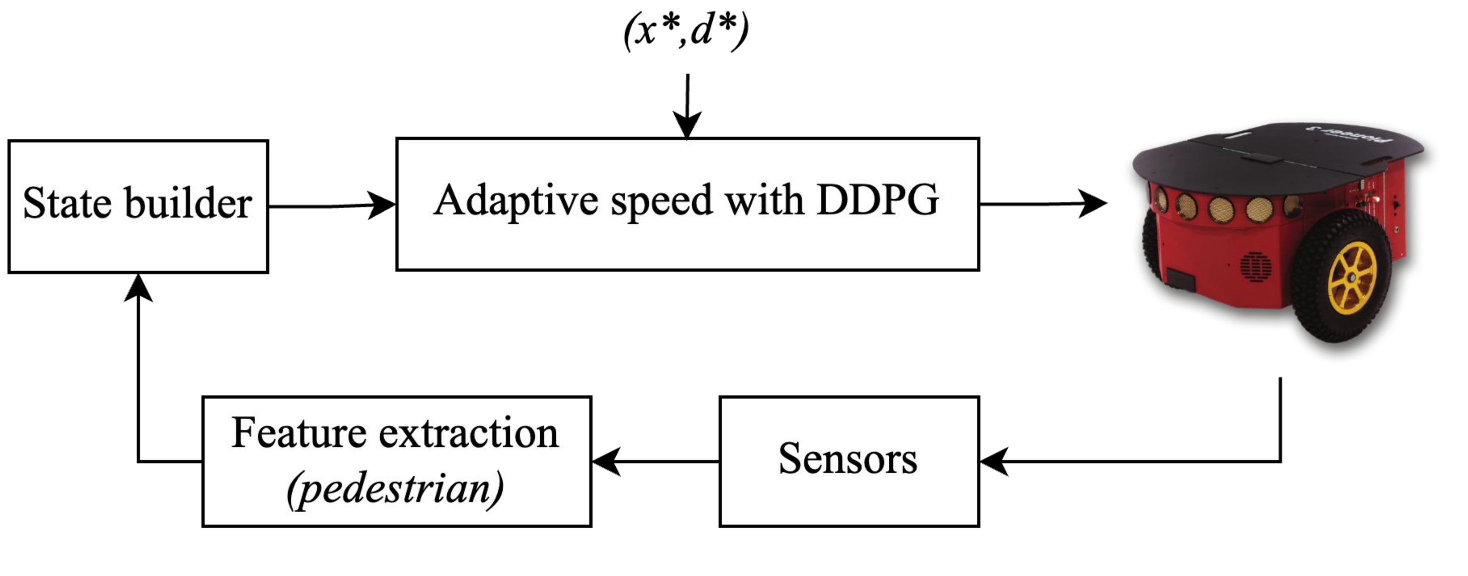

Fig. 3 - Event-Based Visual Servoing for Robot Navigation Pipeline.

Event-based high-speed pedestrian detection

- Detecting people in high-speed motion is an issue for frame cameras. We use event cameras (free of blur motion) and train a YOLO network on pedestrian data.

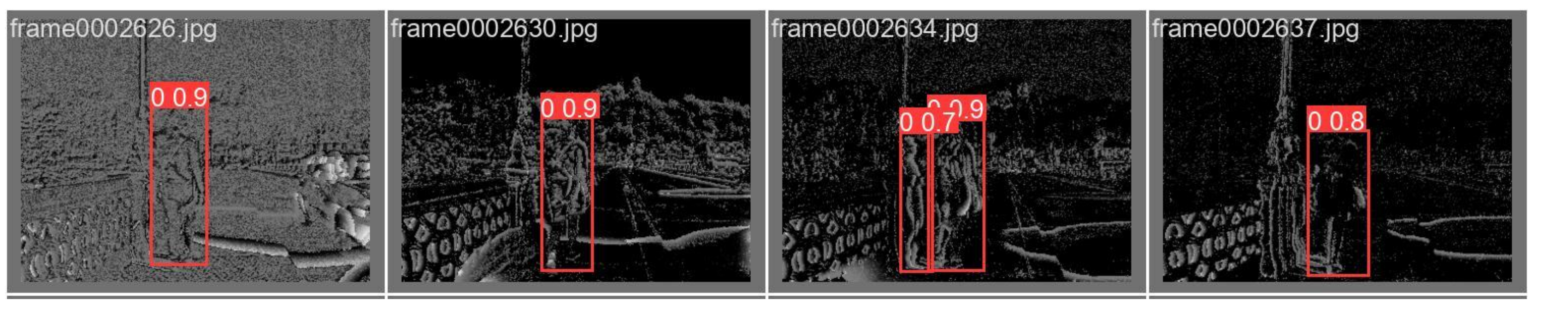

Fig. 4 - YOLOv5s detector on the PEDRo database.

Reinforcement Learning for Robot Navigation

- The state $s_t = [v, w, x_{\text{box}}, d_{\text{ped}}, d_{\text{obs}}, \theta_{\text{obs}}]$ contains the robot's linear and angular velocities, the pedestrian bounding box center, the distance to the person, and the distance and angle to the closest obstacle.
- Actions $a_t = [\Delta v, \Delta w]$ are continuous increments for linear and angular velocities (applied for 0.1s).
- The reward function encourages staying centered on the pedestrian and keeping a target distance of 2m:

$$r_t = \begin{cases} 500, & \text{if } |e_x| < 1 \text{ pix and } |e_{d_{ped}}| < 0.1 \text{ m}, \\ -500, & \text{if } d_{\text{obs}} \leq d_{\text{col\_min}}, \\ -500, & \text{if } d_{ped} > 3 \text{ m or } d_{ped} < 1 \text{ m}, \\ r_{t_{eq}} & \text{otherwise. } r_{t_{eq}} = -k_{\text{dist}} \cdot |e_{d_{\text{ped}}}|^2 - \left(\dfrac{k_x}{1+\alpha |e_{d_{\text{ped}}}|^2}\right) \cdot |e_x|^2 \end{cases}$$

DDPG applied to estimate velocity increments

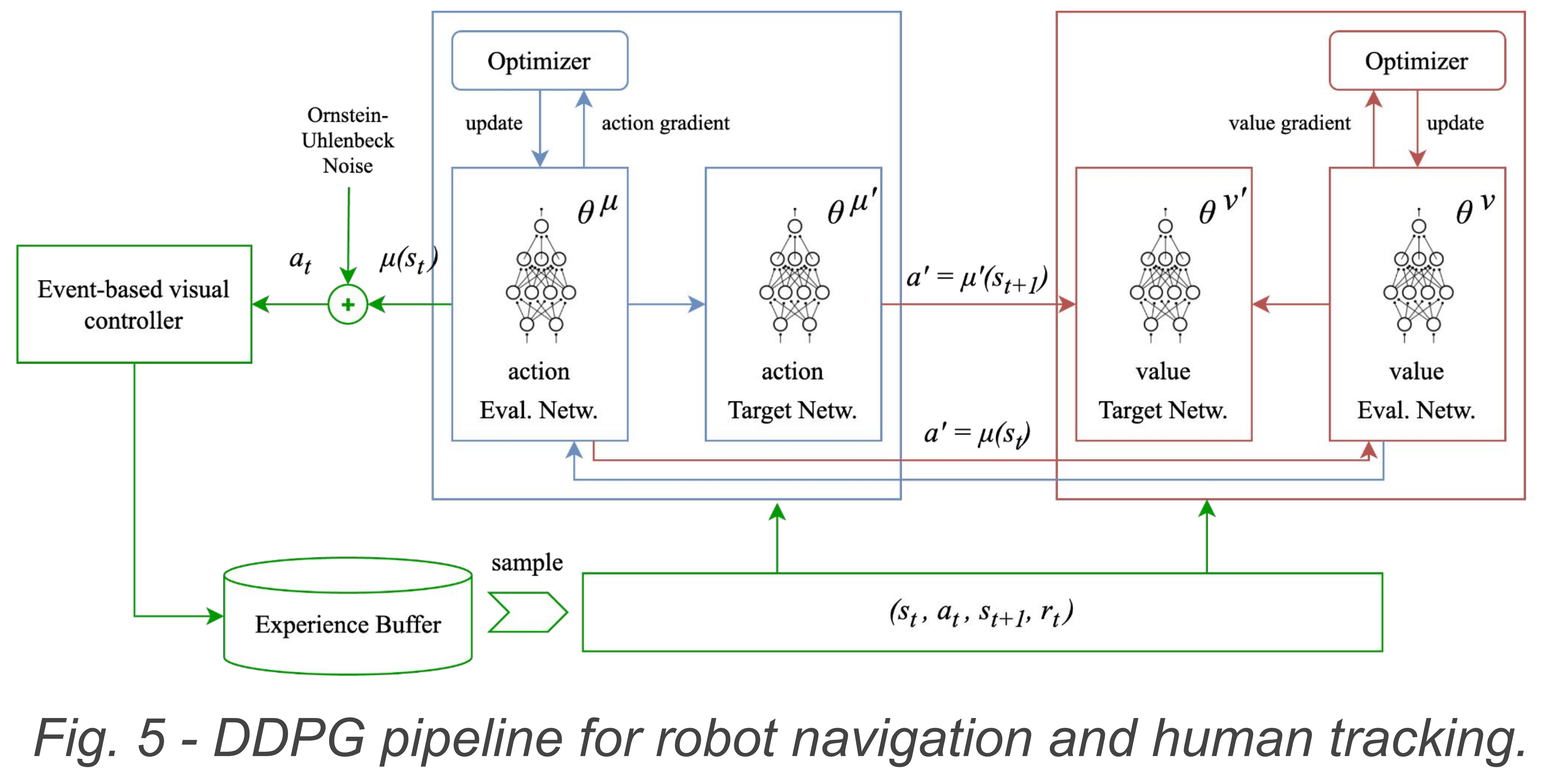

Fig. 5 - DDPG pipeline for robot navigation and human tracking.

Results

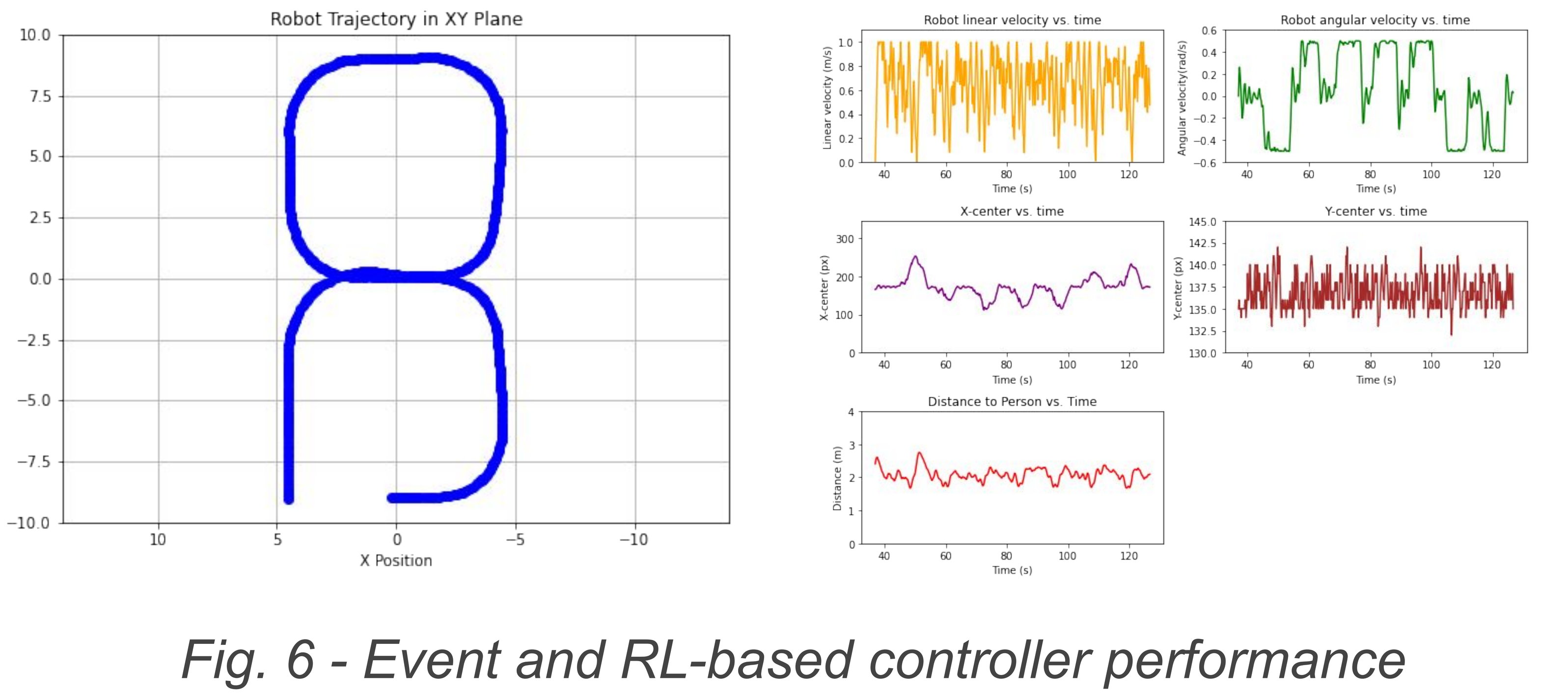

Fig. 6 - Event and RL-based controller performance

Summary / Conclusions

- Event-based RL ensures stable human following.
- Multimodal feedback enables adaptive tracking.
- Next: TD3, refined rewards, sim2real validation.