Summer Reading 10: Proactive And Smooth Maneuvering For Navigation Around Pedestrians

Social Robot Navigation Project @ Bot Intelligence Group

Paper:

Proactive And Smooth Maneuvering For Navigation Around Pedestrians

Maria Kabtoul1;2, Anne Spalanzani1 and Philippe Martinet 2

Summary:

Abstract

- Navigation in close proximity with pedestrians is a challenge on the way to fully automated vehicles. Pedestrian friendly navigation requires an understanding of pedestrian reaction and intention.
    - Merely safety based reactive systems can lead to sub-optimal navigation solutions resulting in the freezing of the vehicle in many scenarios.
    - A strictly reactive method can produce unnatural driving patterns which cannot guarantee the legibility or social acceptance of the automated vehicle.
- This work presents a **proactive maneuvering method** adapted to navigation in close interaction with pedestrians using a dynamic channel approach.

Introduction

- The shared navigation space results in a coupled pedestrian-vehicle planning problem, where the navigation requires cooperation between the two parties.
- Ignoring the cooperation between the two parties can lead to the freezing of the vehicle and not just in highly dense spaces
    - This problem can occur even with one-human interactions if the agent is navigating in close proximity.
- Interpreting pedestrian behaviors and conveying a legible trajectory is essential for the success of this cooperative navigation task.
- To produce natural and legible vehicle trajectories, human-like navigation is often adapted.
- While unstructured environments do not impose strict driving roles, it remains beneficia to adapt such techniques (strict driving roles), as any maneuver which does not resembles the driving patterns of experienced drivers is considered unnatural and illegible to pedestrians
- In this work, a proactive and natural maneuvering is suggested for navigation around pedestrians. The work implements a two-step method for the local steering of the vehicle:
    1. The space is explored and dynamically divided into a set of channels using a local segment of the global path.
        - The cost of navigating in each channel is computed and an optimal channel is found using a fuzzy cost model.
        - The center line of the selected channel is then supplied as a goal path to the second layer of the local navigator to compute the steering controls.
        - To convey a human-like steering behavior, a smooth lane change maneuver is adapted to travel between channels using a Quintic transition path.

2. In the final stage, the exact tracking control commands are derived using a sliding mode control method.

Background, Terms, and Notations

- Global Cartesian Coordinates map frame: (O, X_G, Y_G)
    - 2 additional local coordinate frames are used:
        - Vehicle's local Cartesian Coordinates frame (O_R, X_V, Y_V)
            - O_R is the center of the rear wheels axes.
            - x_v is in the direction of the longitudinal velocity of the vehicle v.
        - Frenet Frame
            - Defined by the tangential and normal vectors a a certain point of a reference curve

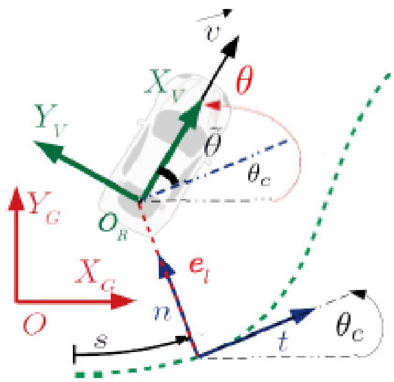


Fig. 1: The vehicle coordinate frames

-
- As shown in Fig. 1, the vehicle's model is defined in the Frenet frame of a path C using the the lateral displacement and the traveled arc length (e_l and s respectively), and the heading error angle between the vehicle and the tangential vector to the path: $\theta = \theta - \theta_C$
- The model is constructed based on social rules and cognitive studies, and learnt using the observed behaviors in real-life recorded pedestrian-vehicle interactions. The model allows to estimate the tendency of an agent to cooperate with the vehicle in a given situation.
- Finally, the method used for the longitudinal control which provides the input *a* (acceleration control input) is the proactive longitudinal velocity controller. This method depends on computing an optimal proactive acceleration control *a* based on a trade-off between 2 criteria:
    - Reducing the social impact of the vehicle on the surrounding pedestrians
    - Increasing the pedestrians cooperation

The Proactive Dynamic Channel (PDC)

- The proactive dynamic channel (PDC) method is based on exploring a look-ahead navigation space of the vehicle and partitioning it to a set of possible navigation options (channels).

    - This partitioning is based on a segment of the global path, which results in a local path modification.

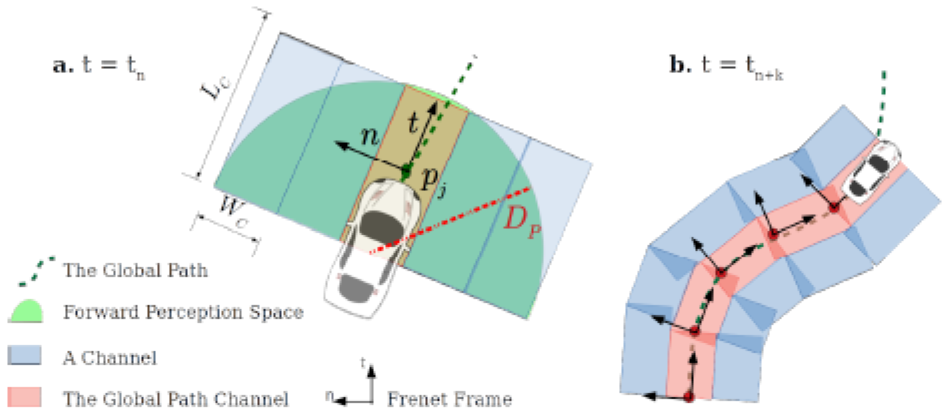


Fig. 2: Dynamic channels construction

-
- The space is globally divided into a set of channels parallel to the global path.
- By computing the set of channels present in the navigation space, the task of finding a valid path is reduced to selecting the optimal navigation channel.
- This decision making step is essential in the proactive navigation framework, as it defines the general direction of the vehicle in the space.
- The navigation cost of each channel is evaluated by assigning a weight to each channel w_c.
    - The higher the weight w_c the more costly is to navigate in this channel in terms of pedestrian discomfort and travel/time cost.

A. The navigation cost of a dynamic channel:

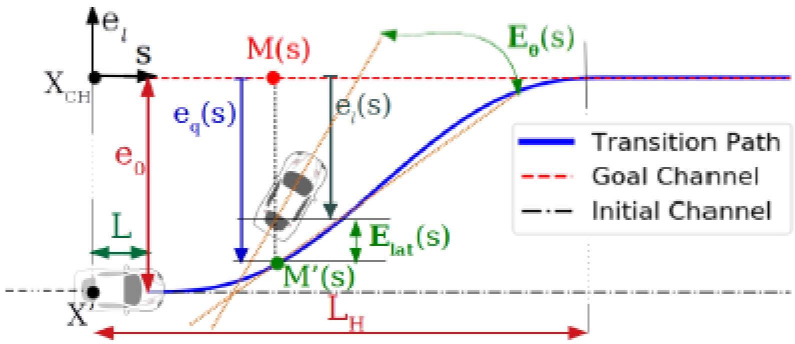
- The first navigation cost weight w_state is based on the state of the channel itself to minimize the discomfort caused to pedestrians navigation in the channel under evaluation.
- 2 additional channel cost weights are defined:
    - The travel cost from the vehicle's current pose to the channel (w_local)
    - The travel cost from the channel back to the global path (w_global)
    - These allow penalizing traveling far distances from the current position of the vehicle or from its reference global path.

B. The channel cost fuzzy model w_state

- To comply with the principals of pedestrian safety and socially-aware navigation, channels with less pedestrians and/or more cooperative pedestrians should be preferred.
- Therefore, the first input used to estimate the channel state cost weight is the pedestrian density in a channel D(t).
- The second input is the expected density change in the channel over a future navigation horizon.
- The third input is the percentage of uncooperative agents in the channel.
- The model rules are constructed to prioritize channels with smaller weights.
- Finally, the channel with the least cost is selected as the goal channel.

Channel-Based Vehicle Maneuvering

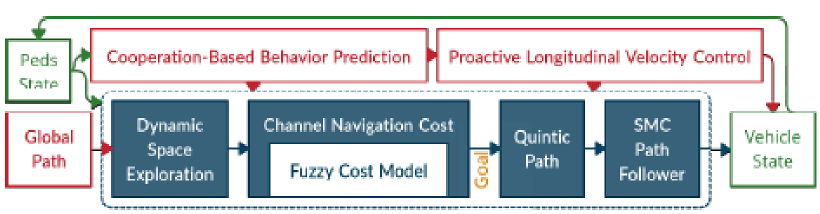
- To maintain a vehicle behavior similar to experienced drivers, a lane change maneuvering is adapted to perform the transition to the selected channel, as lane change maneuvering generates natural and legible vehicle trajectories.
- A Quintic spline candidate which can guarantee a C2-continuous path is used as a transition candidate.



- Fig. 3: Channel transition with the Quintic spline

A. Local Steering control: Path Following
    - SMC (Sliding Mode Control) is a nonlinear control technique that drives the target system to a designed surface in the state space, then keeps the system in a close neighborhood of this surface in a sliding (switching) manner.
    - The sliding mode steering controller is constructed using two tracking errors:
        - Lateral Displacement Error
        - Heading Error
        - This ensures the tracking of the path and the human-like maneuver while satisfying the smoothness in the vehicle heading as well. This can also contribute to the comfort of the vehicle's passengers

Simulations and Results



- Fig. 5: The overall proactive maneuvering system

A. Performance Measures
    - The method is evaluated using some performance measures:
        - Soothness of vehicle's path

    - Pedestrian comfort
    - Safety of the navigation

Conclusion

- This work presented a local maneuvering technique adapted to autonomous vehicles navigation in shared spaces with pedestrians.
    - The method was tested using the PedSim simulator under ROS and compared with the Risk-RRT method.
    - The test simulations included frontal and lateral crossing interactions between a vehicle and a group of pedestrians.
    - The performance was evaluated based on pedestrian safety and control.
- The suggested navigation system managed to maintain the minimum required pedestrian comfort in the reference study, while maintaining a good safety level and a high success rate as compared to the reactive Risk-RRT method.
    - However, our results showed a limitation in the method during lateral crossing interactions. During these interactions pedestrians experienced higher levels of uncomfortableness and side collisions.

Glossary: