Reactive Trajectory Planning and Tracking for Pedestrian Aware Autonomous Driving in Urban Environments

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Agenda

- Problem
- Input Subsystems
- System Architecture
- Trajectory Planner
- State Transition Graph
- High Level Planner
- Implementation
- Summary

Autonomous Urban Driving

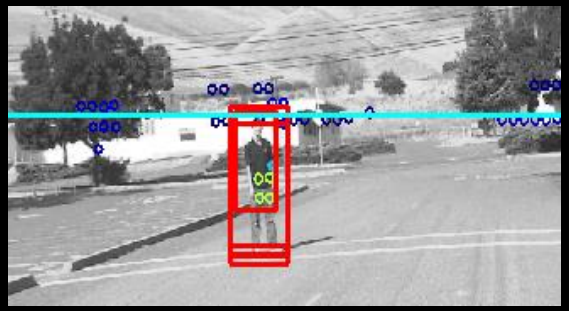
- Level II Autonomy (NHTSA)
- Travel autonomously from start to destination while honoring traffic laws and avoiding pedestrians in the roadway
- Assume no other traffic on roadway

Desired Behavior:

- Minimize time to travel
- Stop and wait appropriate amount of time at Stop signs
- Stop, slow down, ignore pedestrians as appropriate
  - Crosswalk / jaywalking
  - On-road / off-road
  - Moving / static

Input subsystems

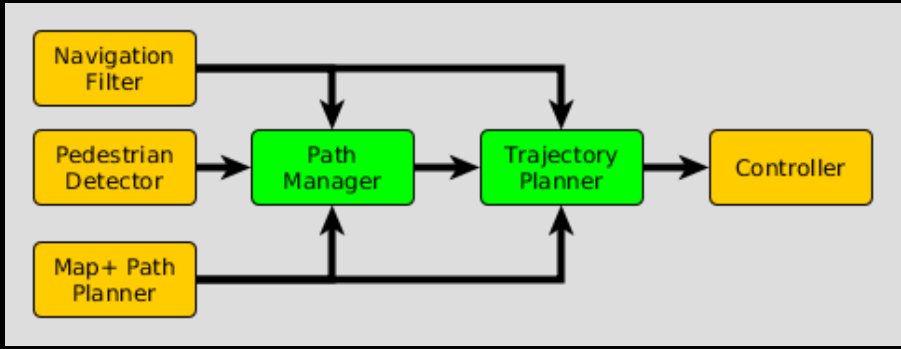
- Path Planner
  - Gives lane level paths
- Pedestrian Detection
  - Using deformable part models with camera, lidar and GPS data
  - Gives location of pedestrian



- Navigation Filter
  - ADMA-G Commercial automotive GPS/INS
  - Receives RTK corrections via cell modem

- High Resolution Map
  - Road extents, lanes, stop signs

System Architecture



Path Manager

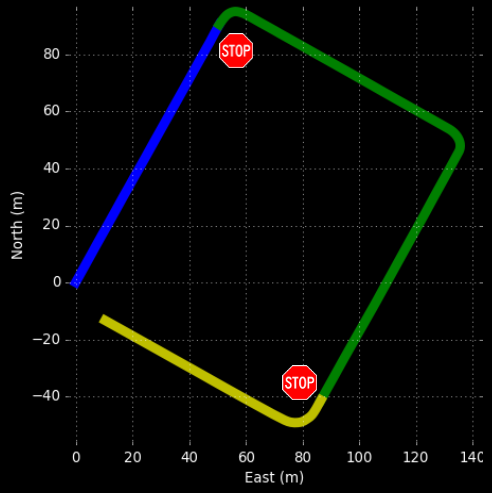
- Implements State Transition Maps
- Stops and restarts vehicle at stop signs
- Governs operation of Trajectory Planner

Trajectory Planner

- Compute medium range trajectories
- Revise trajectories to react to pedestrians
- Input next 2 seconds to controller @ 10 Hz

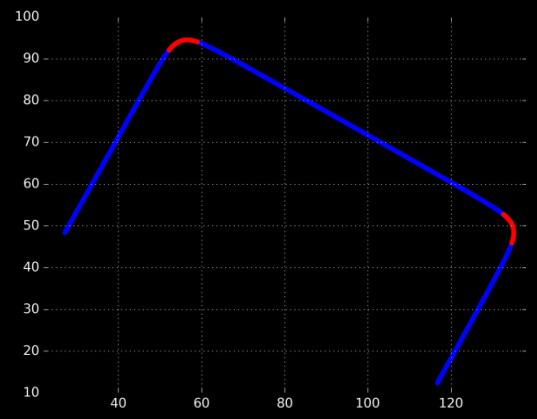
Software Controller

- Governs engine brake, speed and steering

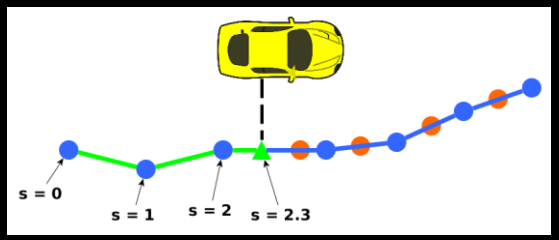


Trajectory Planner

- Solution by parts
  - Segment path with kinematic constraints
    - Acceleration and curvature limit speed
    - Legal speed limit
  - Plan trajectory for each segment and unify
- Time parameterize the trajectory
  - Planned time matched to real time by distance travelled so far on the path



Segments in 2D path

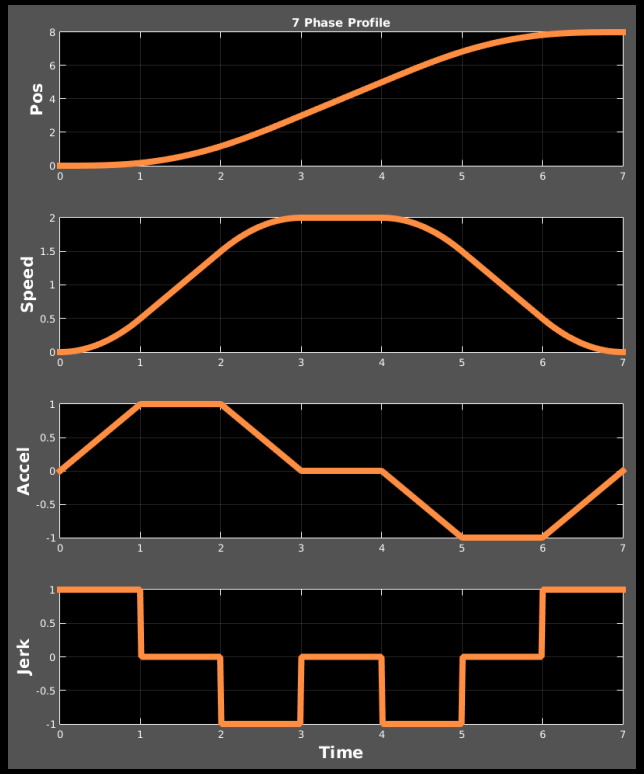


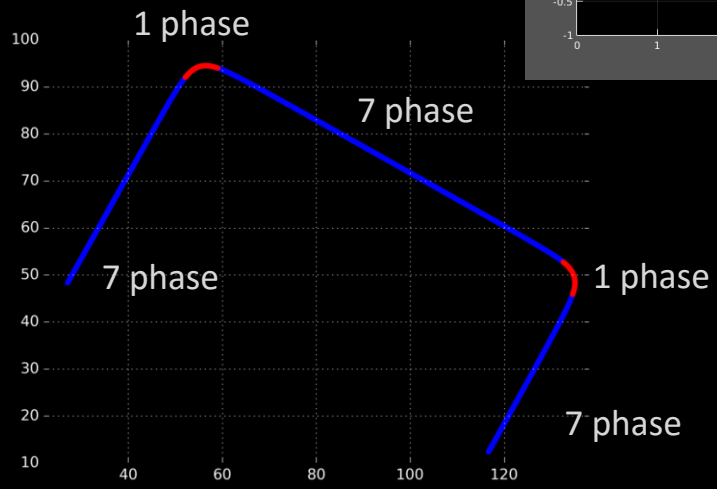
Trajectory Segment Solution

In each segment
- Limit acceleration, jerk, and speed
- Design constant jerk intervals with closed-form solution

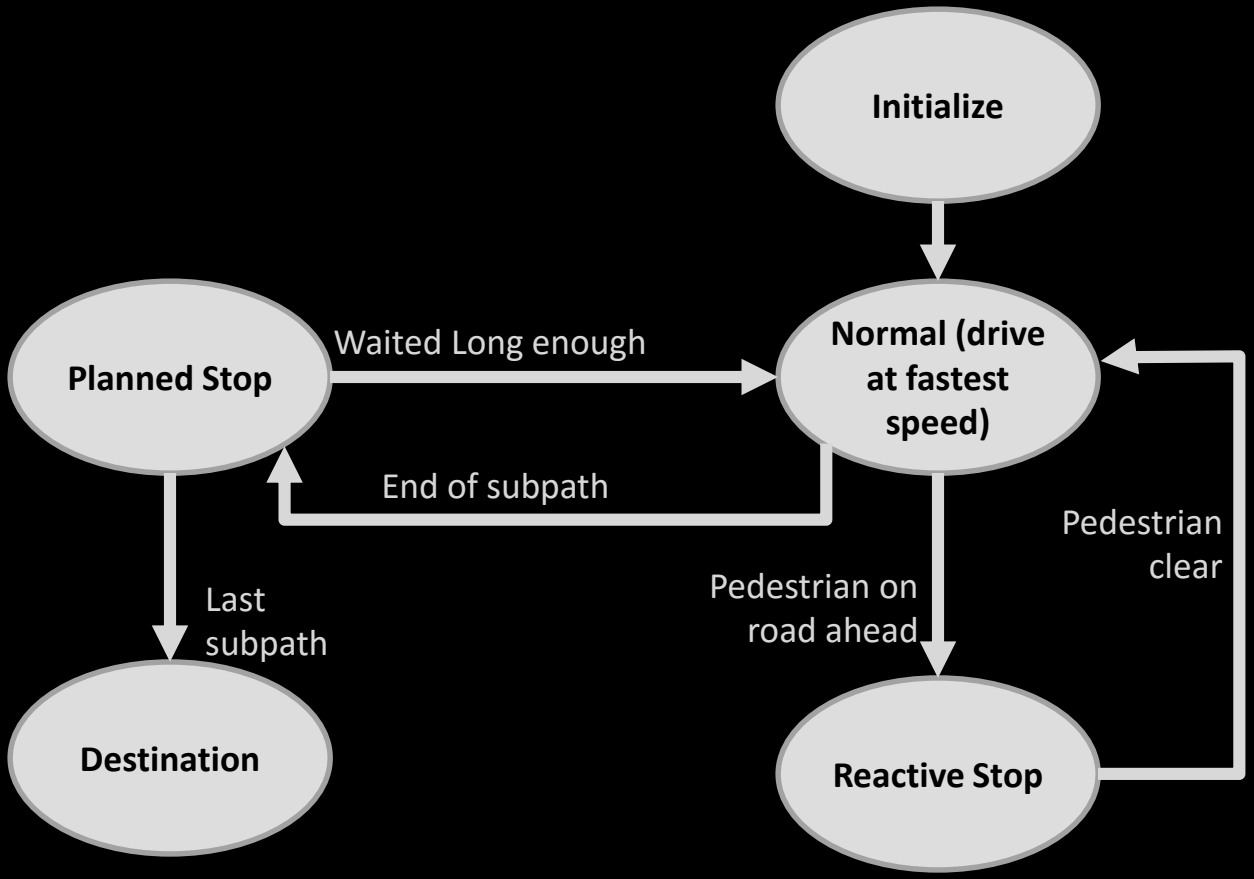
Attempt most time-optimal solution first
- 7 → 6 → 4 → 4R → 3
- No speed change: 1 phase

General Solution
- Integrate j(t)
- Know s(t), v(t), a(t)
- Solve for time intervals

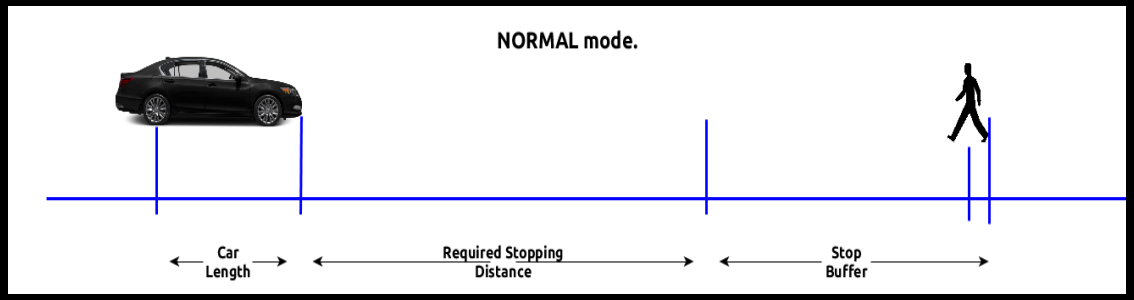




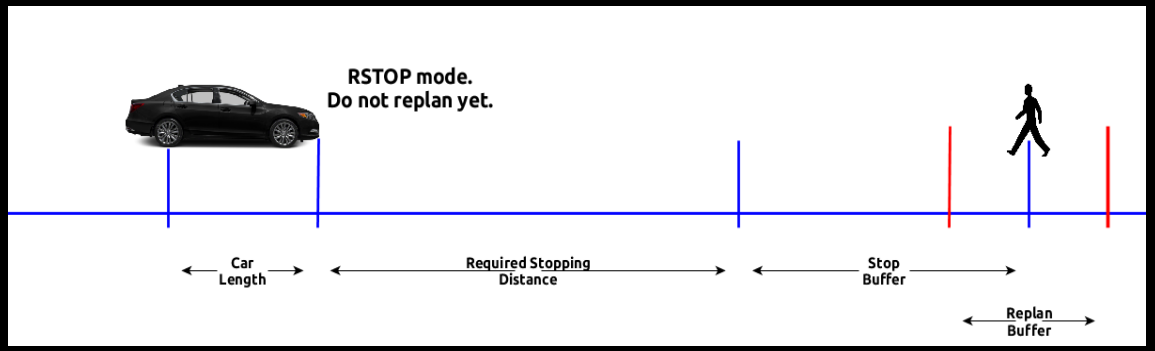
State Transition Graph



Pedestrian Reactivity

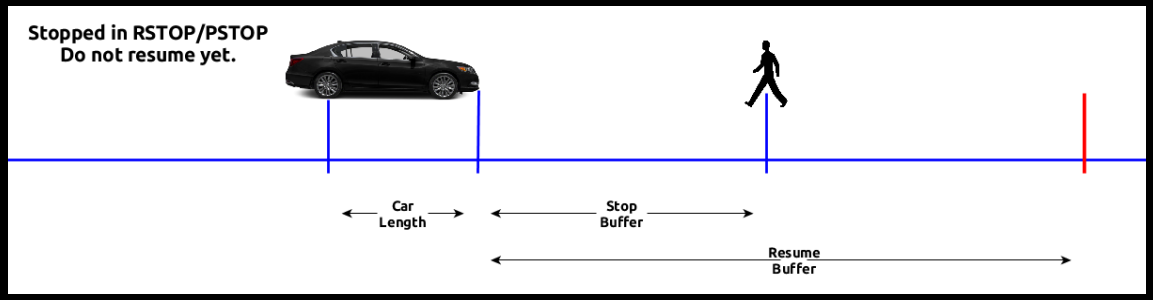


- Project pedestrian position to time parametrized path
- Consider closest pedestrian only
- Execute a 3 phase stop profile when available distance ≤ required distance



- Revise trajectory if pedestrian moves outside replan buffer

Back to normal driving



- Fully stopped? Transition to normal state when:
  - Pedestrian leaves roadway
  - Pedestrian moves farther past the replan buffer
  - Have stopped for 2 seconds at stop sign
- Slow down without stopping where appropriate

Implementation

- System tested 100+ hours
- Planner online operation @ 10 Hz
- Our planner handled corner cases gracefully
- Demo worked 35 times in closed course with no disengagements

Extensions

- Support self-intersecting, overlapping paths
- Perceive and stop for red-lights
- Handle other roadway traffic, change lanes

Summary

- We built a system for trajectory planning
  - Demonstrated use in Level II autonomy framework
  - That is reactive to pedestrians
  - Limits jerk, velocity and acceleration

- System has been tested with over 100 hours of testing

Questions?

State Transition Graph