Automated Driving using External Perception

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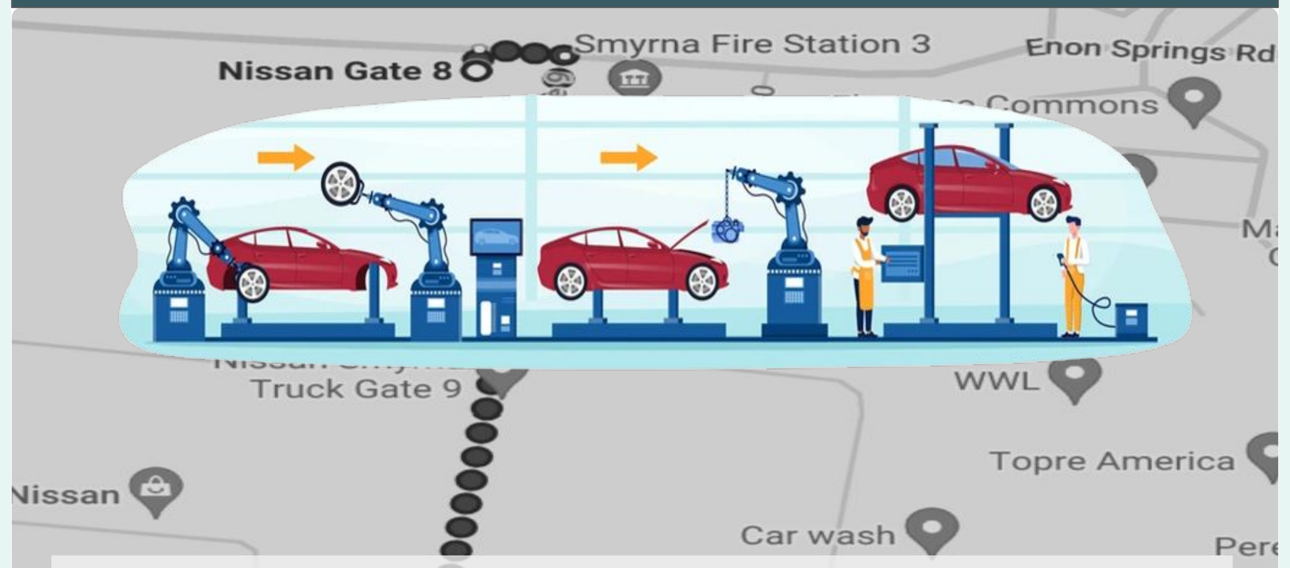
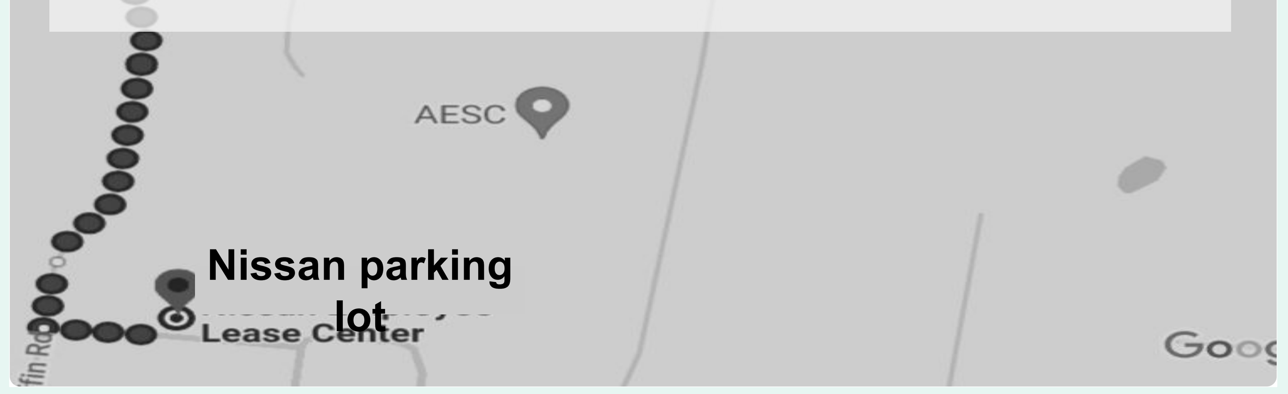
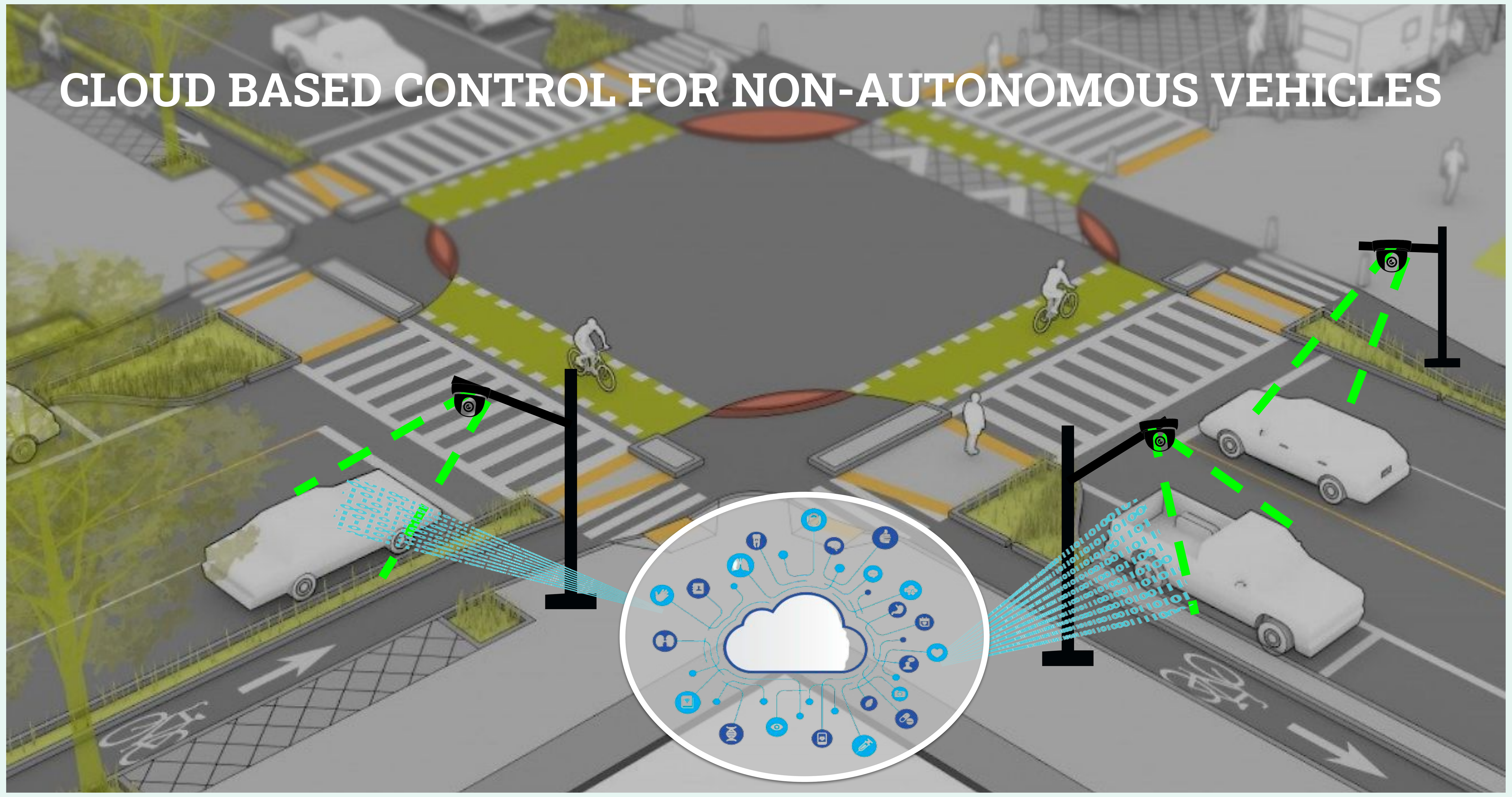
Problem statement / Use Case

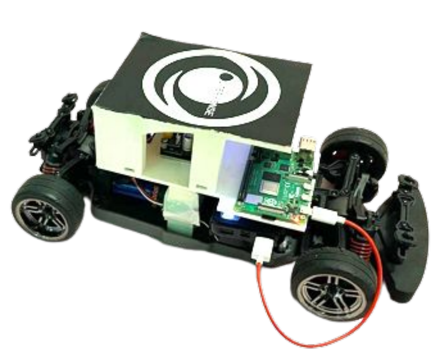


- Automobile manufacturers produce over 1000 cars a day
- The long queue of assembled vehicles is a huge problem for automakers
- These vehicles need to be manually driven from manufacturing plant to shipping yard or parking lot located few miles away
- Using human drivers to marshal these cars is an expensive, time consuming and repetitive process.





Hardware setup



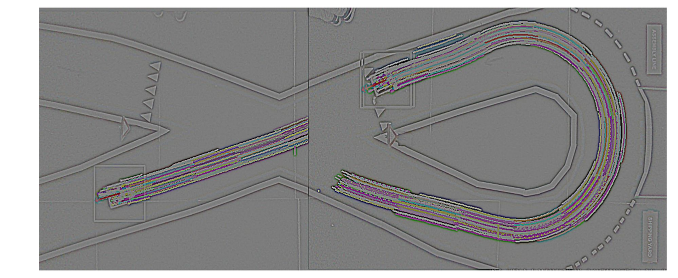
RC car with drive-by-wire capability

Infrastructure with perception sensors

Perception

Multi-object detection and tracking

- High frequency optical flow for object tracking corrected by periodic updates from detection.



Detection:

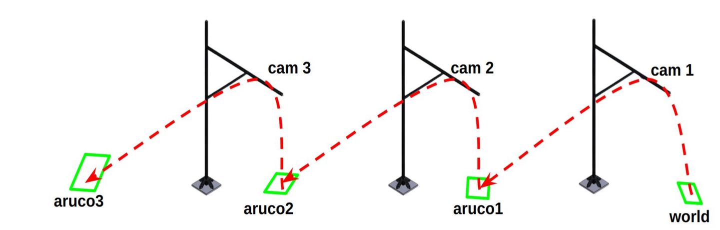
- AruCo markers for controlled vehicles
- Outersense logo detection using Hough transform for obstacles and other objects in the scene

Tracking:

- Pyramidal Lucas Kanade optical flow on SIFT keypoints for velocity and heading estimation

Extrinsic calibration

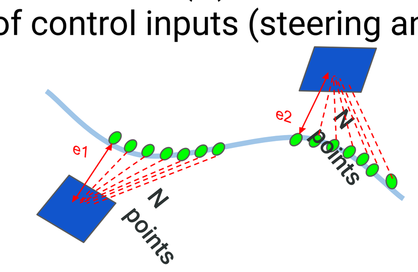
- Multiple cameras calibration with respect to each other using pose estimates of shared AruCo. Parameters are refined using bundle adjustment.



Control System

Model Predictive Control (MPC)

- Cost is errors between desired state and current state (x,y,v,theta)
- Constraints on steering and acceleration
- Optimises over a prediction horizon(N) and minimizes error for N states
- Generates a sequence of control inputs (steering and acceleration)



MPC Formulation

$$\min_{x_{1:N+1},\, u_{1:N}} \sum_{i=0}^{N} \left[\frac{1}{2}(X_{\text{ref},i} - X_i)^T Q (X_{\text{ref},i} - X_i) + \frac{1}{2} u_i^T R u_i\right] + \frac{1}{2}(X_{\text{ref},N+1} - X_{N+1})^T Q_f (X_{\text{ref},N+1} - X_N) + \sum_{i=0}^{N-1} \left[\frac{1}{2}(u_{i+1} - u_i)^T R (u_{i+1} - u_i)\right]$$

$$\text{st} \quad \begin{aligned} & X_0 = X_{\text{initial}} \\ & X_{i+1} = AX_i + Bu_i + C \quad \text{for } i = 1, 2.\dots.N \\ & u_{\min} \le u_i \le u_{\max} \quad \text{for } i = 1, 2.\dots.N \\ & (u_{i+1} - u_i)/\text{dt} \le \Delta u_{\max} \quad \text{for } i = 1, 2.\dots N-1 \end{aligned}$$

Cruise control

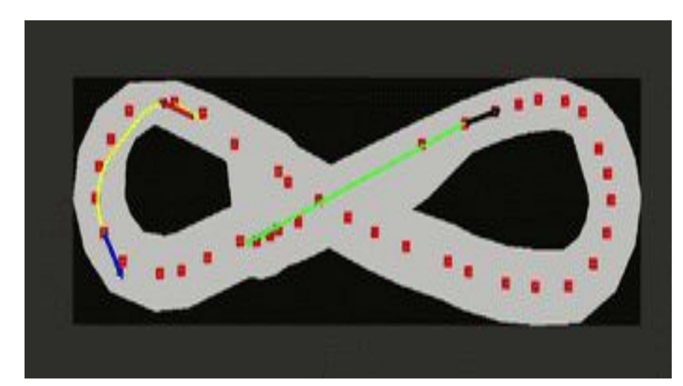
- PD controller to maintain safe distance between controlled vehicles

Planning

Real time hybrid A* planner with kinodynamic constraints

- Takes ego state, static and dynamic obstacle, lane boundaries as input.
- Motion primitive using Reeds-Shepp path.
- Heuristics captures distance to goal, vehicle orientation and ability to reach goal with vehicle constraints.
- Cost function consists of distance travelled, smoothness of path, distance from obstacle and vehicle speed
- Monitors environment and vehicle state, triggers necessary re-plans, generates plans from the vehicle or gives centreline as plan.

Planning performance



- Generates plan to follow centreline
- Stops vehicle to avoid collision with pedestrians
- Finds alternate path to avoid collision with static obstacles
- Handles vehicle behavior at intersections

Sensor fusion

Need for sensor fusion

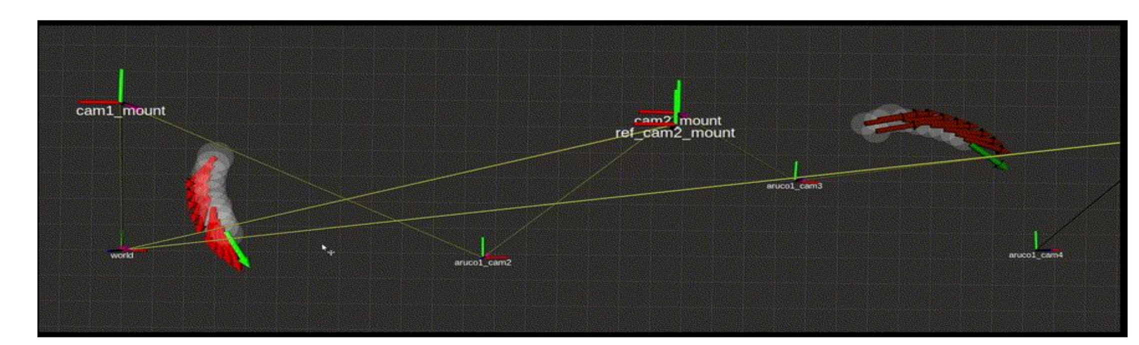
- Noisy yaw estimates and calibration errors
- Temporary loss in tracking

Input sources

- **Odometry** : measured from vehicle steering angle and E-RPM
- **IMU** : measured acceleration and angular velocities
- **Perception**: pose estimates from perception subsystem

Delay-aware Fusion

- Unscented Kalman Filter to fuse odometry, IMU data and state estimates from perception to output more accurate state estimation



Perception estimates   Fused estimates

This project was sponsored by
Nissan Advanced Technology Center (https://natcsv.com/)

Special thanks to:
Liam Pederson, Viju James and Pratham Oza

Outersense

Results

- Vehicle stays within 75% of lane width
- Achieved desired speed more than 10 mph
- Emergency stopped vehicle within 2 seconds
- Avoids collision with static and dynamic obstacles

POC on scaled down model

Conclusion

In summary, using external perception and cloud for non-autonomous vehicles shows promise, but challenges like communication latency and pose estimation inaccuracies need addressing for its successful implementation

External perception   Drive-by-wire   Off-board control