DEVELOPMENT OF A CONNECTED AND AUTOMATED ELECTRIC VEHICLE WITH 4 IN-WHEEL MOTORS

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2019 Annual Merit Review

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eems070

OVERVIEW

TIMELINE

Project Start: July 2, 2018
Project End: July 1, 2019
Percent Complete: 80%

BUDGET

Total Project: $ 150,000
Total Spent (Dec 2018): $ 38,560

BARRIERS

OEM Development Schedule
Test Facility Access
Limited Budget

PARTNERS

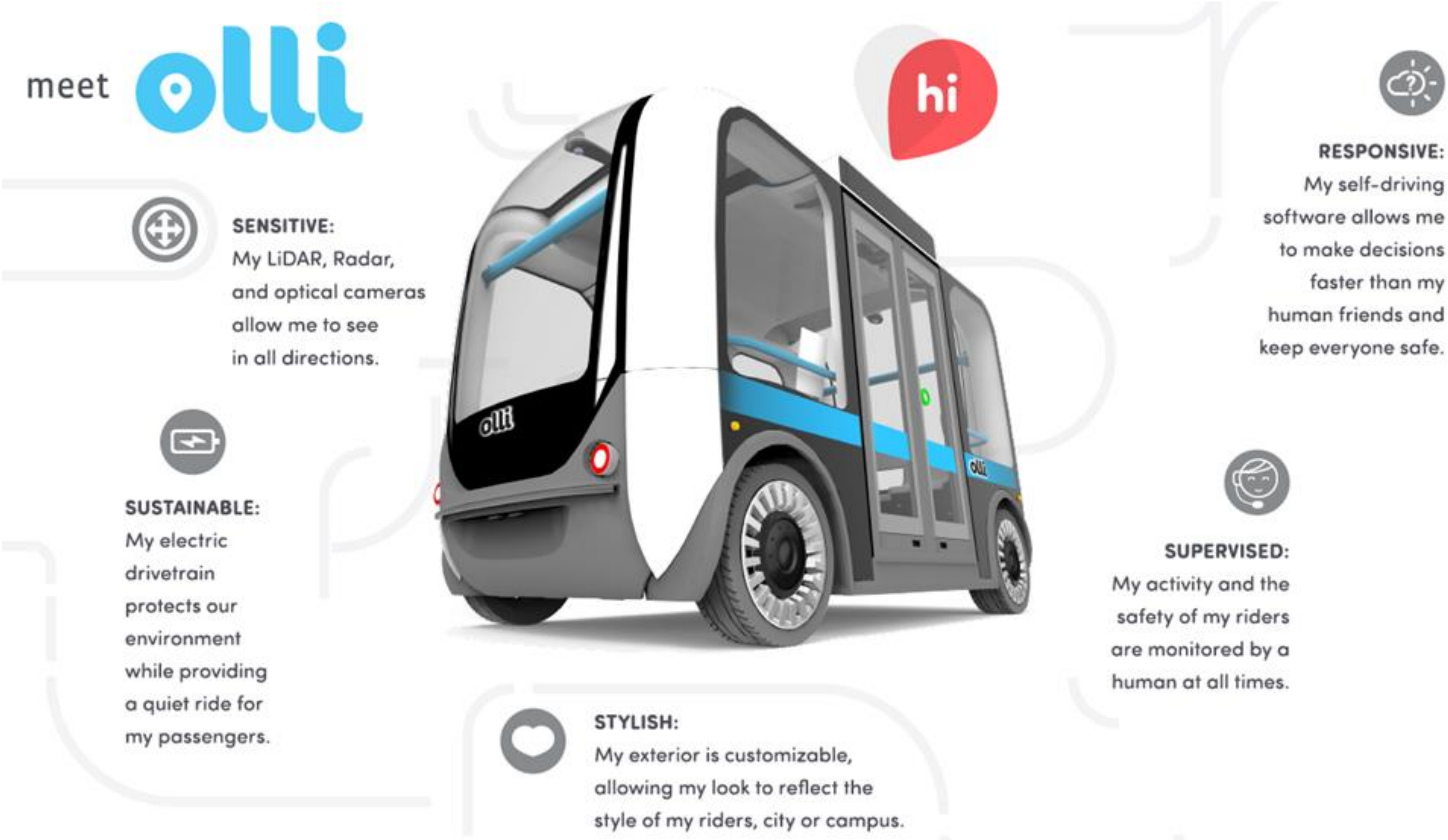
Local Motors
Arizona State University

Relevance

OBJECTIVES: Phase 1

- To use the redundant control degrees of freedom enabled by independent, in-wheel motors and the V2X information obtained from vehicle connectivity, including SPaT and V2V traffic information to optimize the control algorithm for maximum energy efficiency of the Olli^{TM} shuttle EV developed by Local Motors.
- An improvement in energy efficiency will assist with commercialization of the Olli vehicle by improving vehicle range and reducing size (and costs) of the energy storage system.
- Phase 2 to focus on further refinement of the algorithms, expansion to additional areas of energy efficiency improvement potential, and integration of the algorithms to the Olli vehicle.

Olli Shuttle Vehicle: Introduction



Olli Shuttle Vehicle: Specifications

RANGE

Average Range	60km/40mi (Nominal) 40km/25mi (Max Load, Max AC)

CAPACITY

Max Passengers	Up to 12*

*Capacity varies based on regulatory restrictions and seating layout.

MOTOR

Max Torque	240Nm
Continuous Torque	125Nm
Max Power	100kW
Continuous Power	30kW
Max Speed	40km/h (25mph)
Type	Brushless Synchronous AC

POWER SYSTEM

Max Capacity (kWh)	18.5 Max (16.2 Usable)
Charger Type	6.6kw Max
Charge Time (230V A/C single-phase)	Approx. 4 Hours

DRIVETRAIN

Transmission	9.59:1 Gear Ratio

SENSORS

LiDAR	2 Std Def, 1 HD
Radar	2F+2R SRR, 1FWD ESR
Internal Measurement Unit	Yes
Optical Camera	Optional
Bumper Switch	Front, Rear
GPS	2 GPS Antennas

COMMUNICATION / DATA

GSM/LTE Modem
On Board Data Recorder

HVAC CONTROLLER

Heating/Air Conditioning Standard

DIMENSIONS

Length	3920mm (12.86ft)
Width	2050mm (6.73ft)
Height	2500mm (8.20ft)
Wheelbase	2526mm (8.29ft)
Passenger Room Height	1950mm (6.40ft)

WEIGHT

Curb Weight	1860kg (4100lbs)
Carrying Capacity	545kg (1200lbs)

CHASSIS / SUSPENSION / BRAKES

Chassis	Aluminum
Front Suspension	Macpherson
Rear Suspension	Macpherson
Front Brakes	Disc
Rear Brakes	Disc
Front Tire	215/50/R17
Rear Tire	215/50/R17
Emergency Brake	Yes

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Approach

Focus Areas

- The energy efficiency improvement objective is being accomplished by establishing three focus areas:
  - Low-Level Powertrain Control (LLPC): Control of the powertrain components, including energy storage system and in-wheel motors
  - High-Level Decision Control (HLDC): Path planning, including speed and acceleration, based on received information
  - Intersection Management (IM): Improvement of traffic flow through an intersection with multiple vehicles

Approach

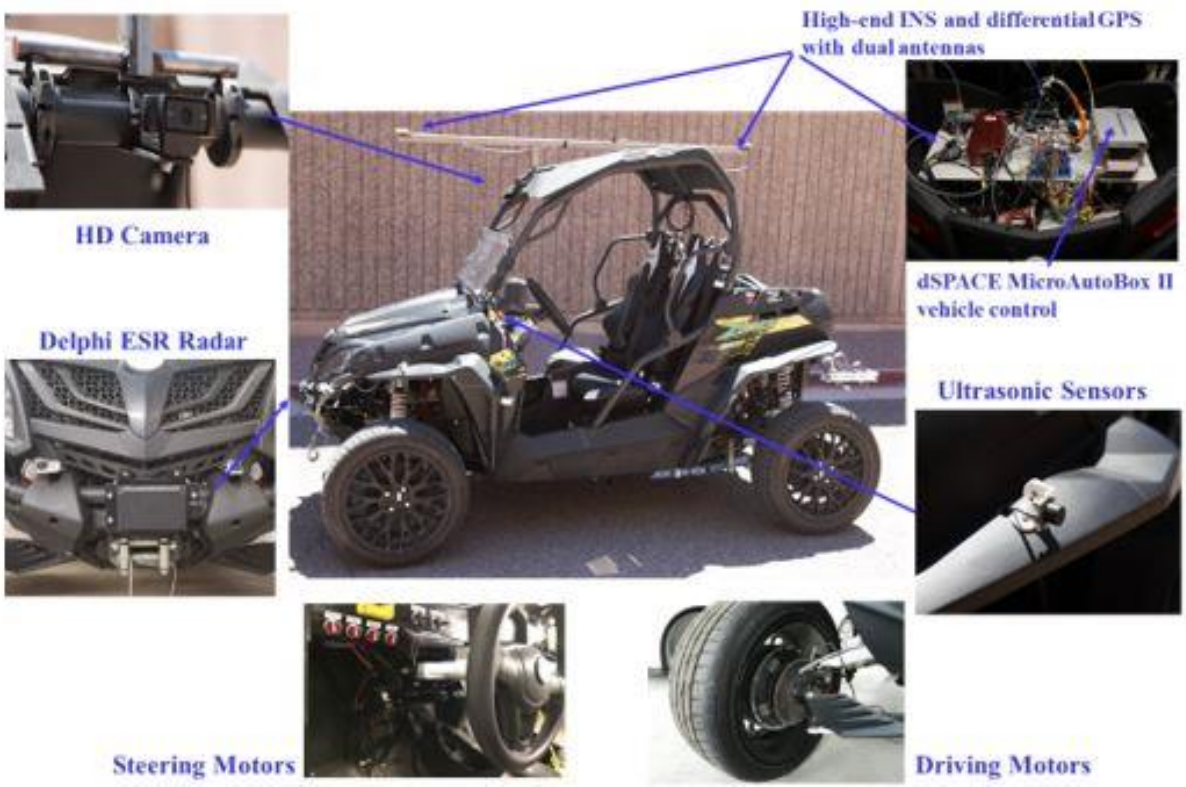
Methodology

- The methodology for achieving project objectives is:
  - Model the Olli shuttle vehicle.
  - Develop algorithms in each of the three areas of energy efficiency focus.
  - Develop an overall control strategy integrating all focus area algorithms.
  - Integrate the overall algorithm into the experimental vehicle.
  - Test the experimental vehicle to validate the simulations.

Approach

Methodology

- The experimental vehicle:



Approach

Low-Level Powertrain Control

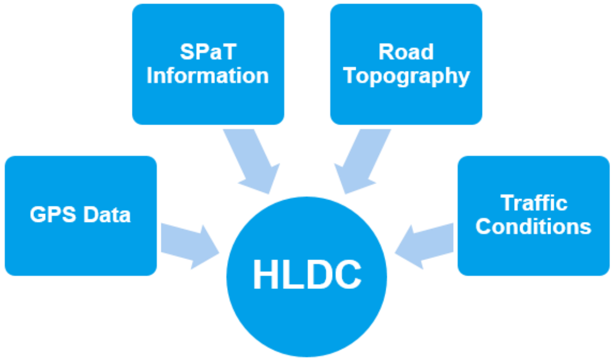
- The goal of the LLPC focus area is to develop control algorithms that increase energy efficiency for a given powertrain design: Central motor (CM, with integrated transmission) vs. In-wheel motors (IWM, with no transmission.)

- The LLPC analysis includes a comparison of two powertrains as Local Motors finalizes the design.

Approach

High-Level Decision Control

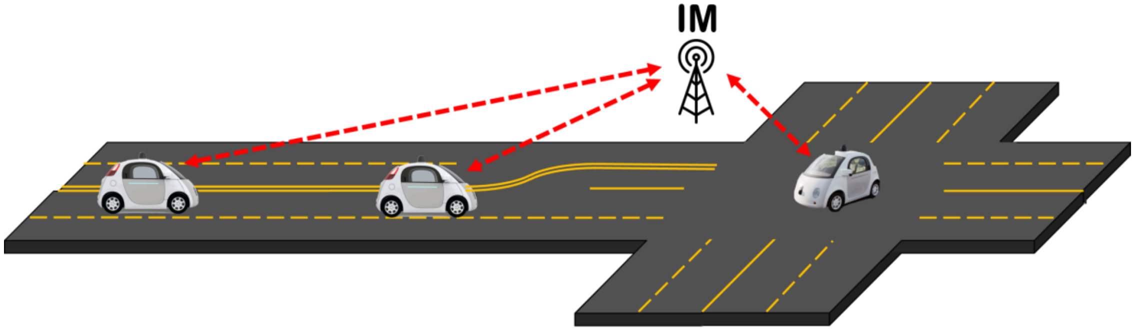
- The goal of the HLDC focus area is to minimize energy demand for a trip based on various inputs for spatio-temporal intervals in a real-time implementation. Inputs include:
  - GPS Data
  - Signal Phase and Timing (SPaT)
  - Road Topography
  - Traffic Conditions



Approach

Intersection Management

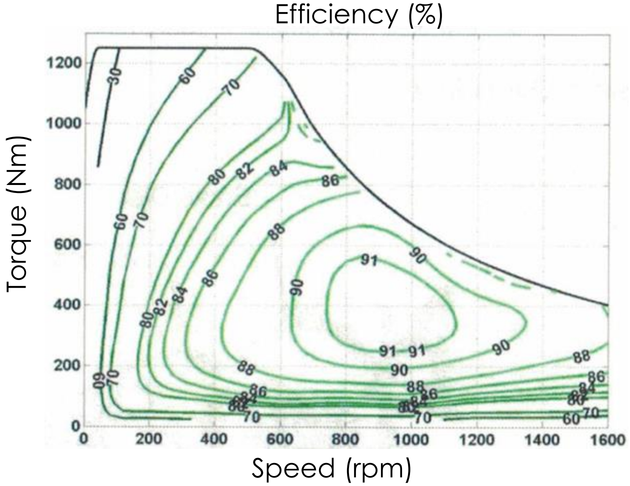
- The goal of the IM focus area algorithm is to maximize throughput while minimizing energy consumption of the vehicles passing through an intersection.
- The system includes communication between the vehicles approaching the traffic signal-free intersection and the intersection manager. The intersection manager dictates the trajectory of each vehicle according to the particular algorithm.



Accomplishments and Progress

LLPC: Central & In-Wheel Motor Comparison

- Analyzed the efficiency maps of the CM (EMRAX 228) and the IWM (PD 18).
- Analyzed the Olli driven by one CM and 2 IWMs in rear wheels (4 IWM version theoretically analyzed as well).
- Analyzed and compared simulation and experimental results.



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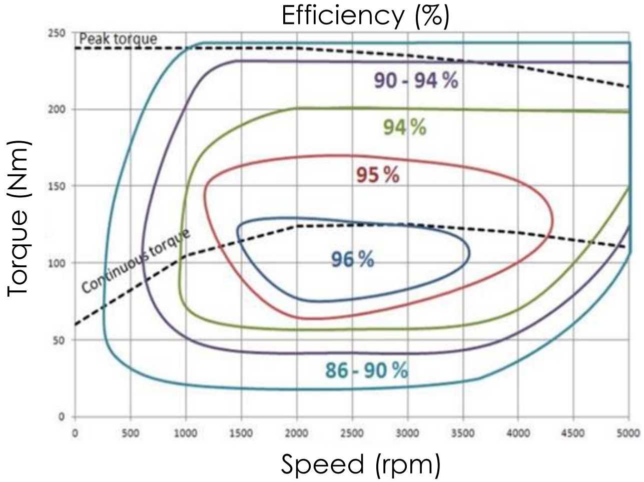
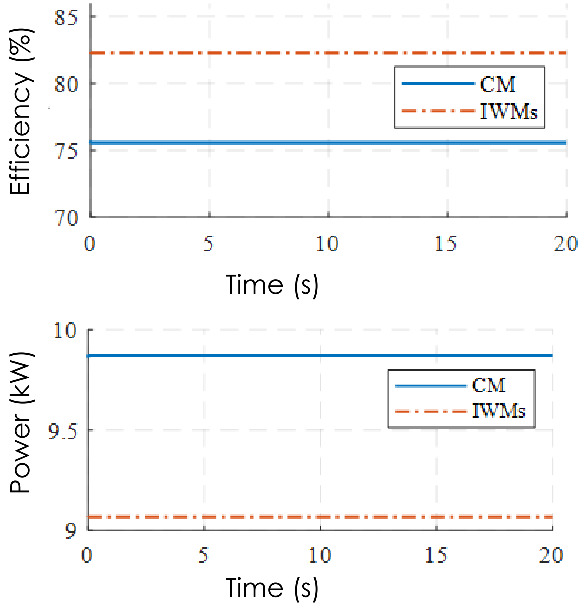


Source: EMRAX

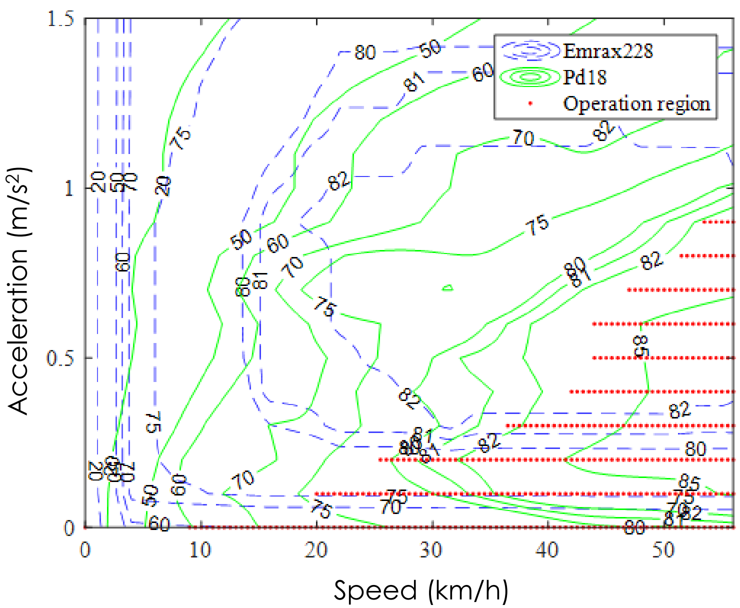
Accomplishments and Progress

LLPC: Simulation Analyses

- Preliminary efficiency analysis indicating power savings for IWMs over the CM.
- Determined vehicle operating region from efficiency maps.
- Analysis for constant-speed cases (5 mph, 10 mph, 15 mph, 20 mph).



Approximately 9% power savings for IWM in comparison to CM

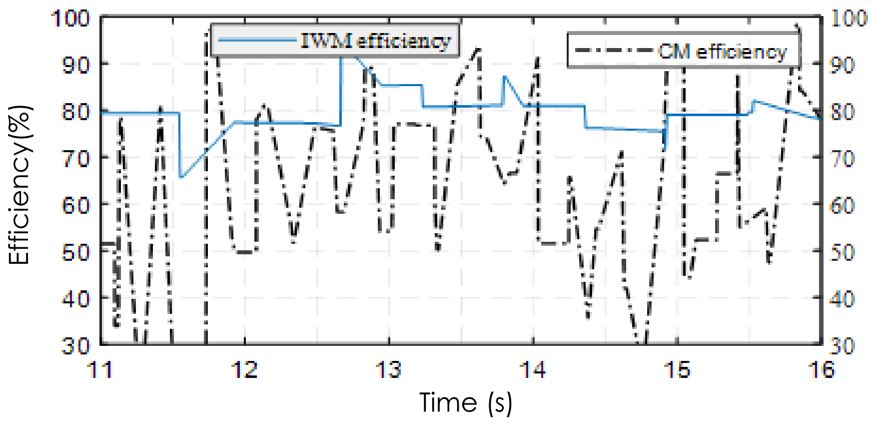


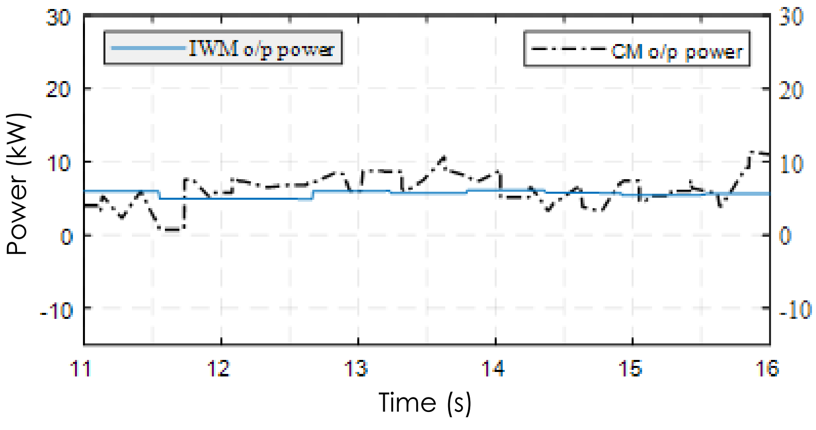
Proposed operating regions based on efficiency maps

Accomplishments and Progress

LLPC: Experimental Data Analyses

- Closed course tests of the two versions of the Olli vehicle were conducted to measure efficiency and power in order to validate the simulation results.
- For similar output power, the IWM version requires less power consumption than the CM version. Optimization of the IWM controls, especially when 2D is considered, will result in further energy efficiency gains.

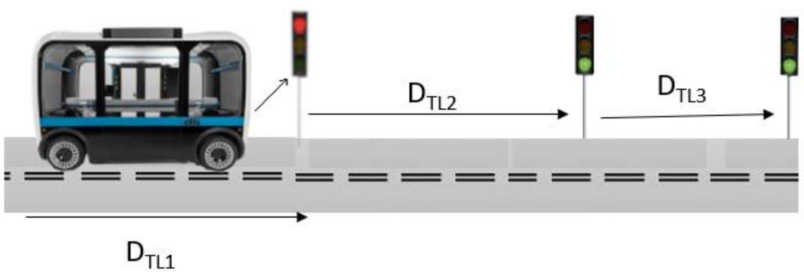




Accomplishments and Progress

HLDC: Algorithm Development

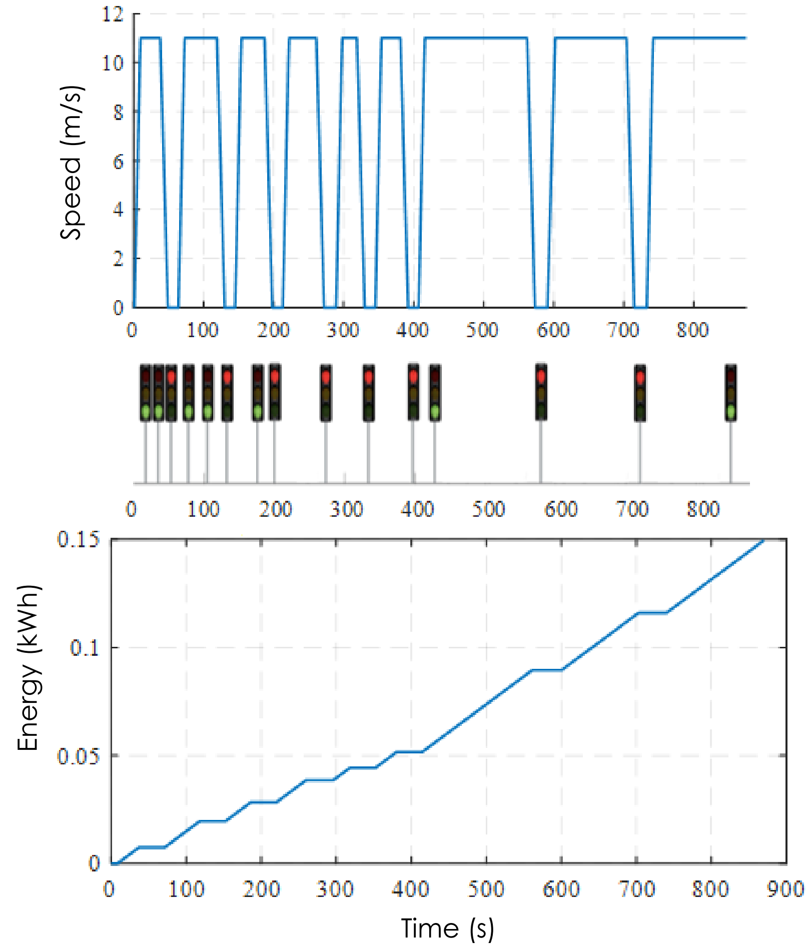
- An algorithm to optimize the speed trajectory of the vehicle in an urban environment was developed.
- The algorithm uses V2X information to reduce trip time and energy consumption.
- Local optimization and road segmentation minimize computational power demand and allow for real-time implementation.
- By using SPaT information and the distance between traffic intersections, the vehicle speed is modulated.



Accomplishments and Progress

HLDC: Algorithm Results - Baseline

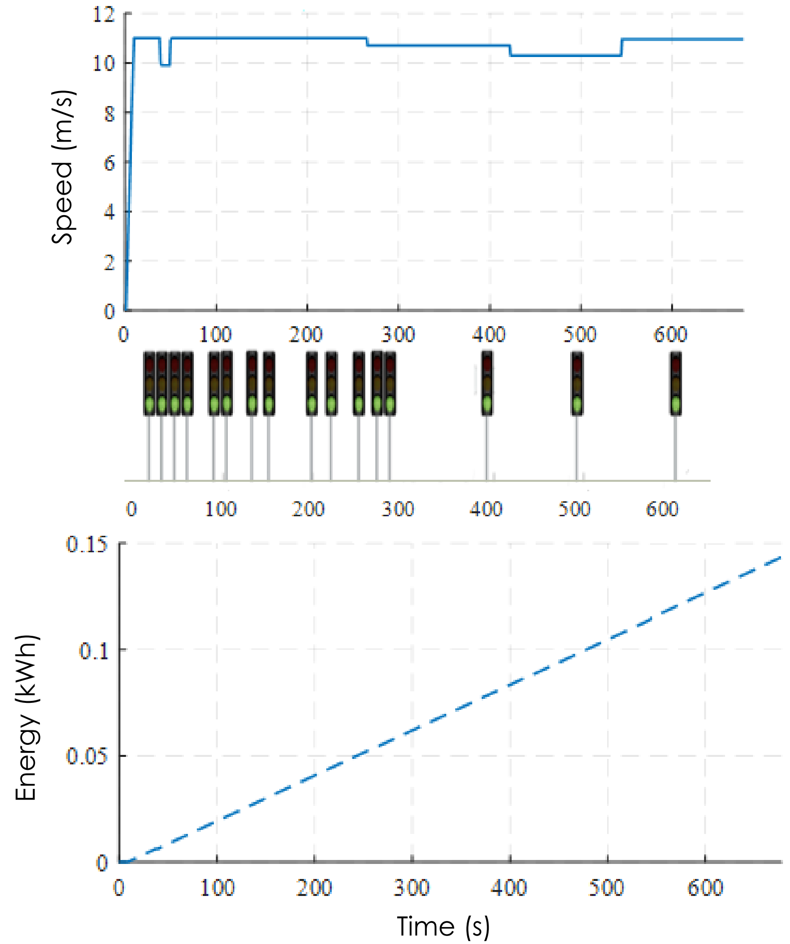
- The baseline algorithm (before optimization) results in multiple stops at traffic intersections. This increases trip time and energy lost due to braking (that cannot be recovered through regenerative braking).



Accomplishments and Progress

HLDC: Algorithm Results - Optimized

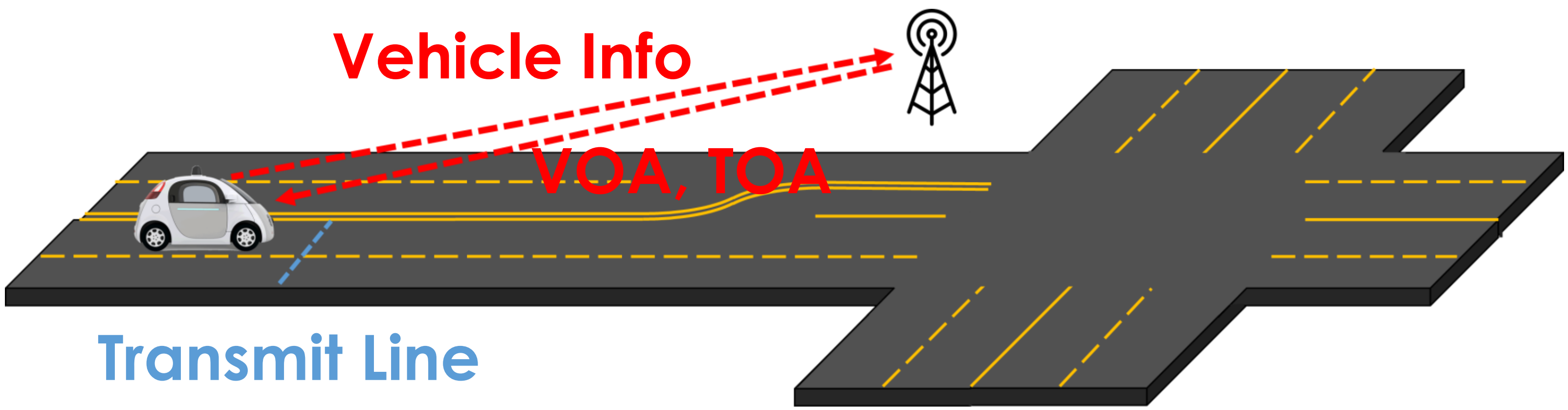
- The optimized algorithm avoids stops at traffic intersections, as well as multiple accelerations and decelerations.
- The optimized algorithm reduces the trip time by 18% and the energy consumption by 10%.



Accomplishments and Progress

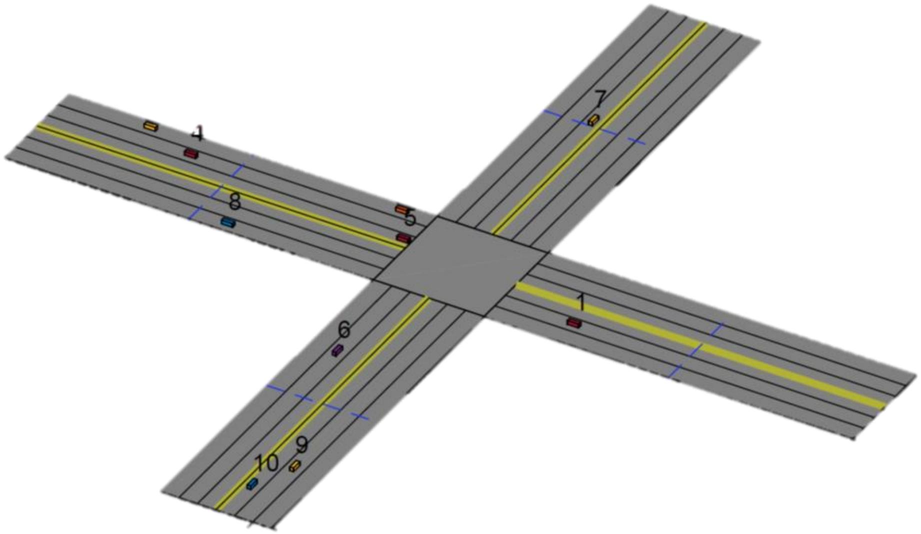
IM: Algorithm Development

- A vehicle transmits its information to the intersection manager upon reaching the Transmit Line (TL).
- Intersection manager assigns a target Velocity of Arrival (VOA) and Time of Arrival (TOA) to the vehicle.
- All vehicles synchronize their clock with the IM.
- IM will ensure that the assigned VOA and TOA are feasible.



Accomplishments and Progress

IM: Algorithm Results



- A 4-way intersection was simulated (60 m X 60 m intersection, 200 m road approaching the intersection from each direction)
- The initial speed of connected and automated vehicle (CAV) approaching the intersection is assigned a random speed between 11 and 33 mph.
- The total number of CAVs simulated was 72.
- The energy consumption for the traffic light and IM situations were calculated. The IM was able to achieve a 30% energy consumption reduction from the baseline traffic light situation.

Collaborations

Academic-Industry Partnership

- Arizona State University
  - Project management
  - Algorithm development
  - Project reporting

- Local Motors
  - Project management
  - Olli vehicle testing
  - Algorithm development

Future Work

PHASE 1

- Complete development of the overall control strategy algorithm that integrates the three focus area algorithms to dictate the speed of the vehicle.
- Conduct simulation of overall control strategy to predict total energy efficiency improvement.
- Integrate the overall control algorithm into the experimental vehicle.

Future Work

PHASE 2

- Conduct closed course testing of the experimental vehicle to validate the simulation results from Phase 1.
- Extend the results of Phase 1 to 2D.
- Integrate the finalized overall control algorithm into the Olli vehicle.
- Conduct closed course testing of the Olli vehicle to validate the simulation results from Phase 1 and Phase 2.

Future Work

PHASE 2 (cont'd)

- Refine each of the three focus areas and add additional complexity to provide further optimization opportunities:
  - LLPC: Consider four-wheel steering and four in-wheel motors for energy optimization of lateral motion.
  - HLDC: Consider route selection and other road users to provide path planning beyond the current speed profile.
- Include thermal management optimization of the Olli vehicle.

Future Work

PHASE 2 (cont'd)

- Integrate complete control strategy into the Olli vehicle.
- Conduct validation testing to enable commercialization of the Olli vehicle.

2019 AMR Summary

- The objective of this project is to develop a novel control algorithm for an EV with in-wheel motors to increase energy efficiency.
- Energy efficiency gains are sought in three focus areas:
  - Low-level powertrain control
  - High-level decision control
  - Intersection management
- The three focus areas have each demonstrated significant energy efficiency improvement separately in simulation.
- The next step for Phase 1 is to complete an overall control strategy that integrates all three focus areas, conduct simulations to predict total energy efficiency gain, and integrate the overall control strategy into the experimental vehicle.